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FIELD MANUAL

FIELD ARTILLERY SURVEY

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HEADQUARTERS, DEPARTMENT OF THE ARMY

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FIELD ARTILLERY SURVEY

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CHAPTER 1
GENERAL

1–1. Purpose

This manual is a guide for commanders, survey officers, and personnel engaged in the conduct of artillery surveys. It provides a basis for instruction, guidance, and reference in surveying principles and procedures and in the operation and care of survey instruments. Procedures covering all situations cannot be prescribed; therefore, these instructions should be used as a guide in developing suitable techniques. The material presented herein is applicable without modifications to both nuclear and nonnuclear warfare.

1–2. Scope

This manual discusses the survey personnel and equipment available to artillery units, the measurement of angles and distances and the determination of relative locations on a rectangular grid system.

1–3. References

Publications used as references for the manual and those offering further technical information are listed in appendix A. The orders of survey accuracy referred to in this manual are listed in appendix H. Forms referenced herein are available through normal A G Publications supply channels.

1–4. Changes and Corrections

Users of this manual are encouraged to submit recommended changes or comments to improve the manual. Comments should be keyed to the specific page, paragraph, and line of the text in which the change is recommended. Reasons should be provided for each comment to insure understanding and complete evaluation. Comments should be prepared using DA Form 2028 (Recommended Changes to Publications) and forwarded direct to Commandant, U.S. Army Field Artillery School, ATTN: ATSFA–PL–FM, Fort Sill, Oklahoma 73503.

1–5. Mission of Field Artillery Survey

The mission of field artillery survey is to provide a common grid which will permit the massing of fires, the delivery of surprise observed fires, the delivery of effective unobserved fires, and the transmission of target data from one unit to another. The establishment of a common grid is a command responsibility.

1–6. Fundamental Operations of Survey

Successful accomplishment of the survey mission is dependent upon the following factors:

a. Planning. Survey planning includes a thorough map and ground reconnaissance, gives full consideration to the factors affecting survey and conforms to basic military principles. Survey planning is an essential prerequisite to the fieldwork.

b. Fieldwork. Survey fieldwork includes the positioning of survey control points, accurate measurement of required distances, horizontal angles and vertical angles and the accurate recording and sketching of all pertinent data. The fieldwork may be initiated before completion of the entire plan if the situation so dictates.

c. Computations. Survey computations include the use of known data and the conversion of appropriate elements of field data to produce required horizontal and vertical locations and directional control. Survey computations are performed simultaneously with the fieldwork.

1–7. Responsibilities of the Corps of Engineers

a. The survey responsibilities of the Corps of Engineers are described in AR 117–5 and FM 5–146. In regard to field artillery survey, Corps of Engineers responsibilities include:

(1) The supply of maps.

(2) The supply of trig lists and other survey control data.

(3) Extension of ground control as described in *b* below.

b. When survey control is not available, the normal procedure is for the survey company of the engineer base topographic battalion (THEATER LEVEL) to extend control to the rear boundary of the army area; the survey company of the engineer topographic battalion (ARMY) to extend control to the rear boundaries of subordinate corps; and the survey platoon of the engineer topographic company to extend control as directed by the corps commander.

c. The establishment and extension of survey control into the corps area are functions of the engineer topographic unit. The surveyors of the field artillery target acquisition battalion extend control throughout the corps area and into the division area.

1–8. General Responsibilites of Field Artillery Units

Each field artillery commander is responsible for insuring that required survey control, consisting of position location, position height, and an orienting line of known direction, is furnished to subordinate units as soon as possible.

CHAPTER 2

FIELD ARTILLERY BATTALION AND BATTERY SURVEY OPERATIONS

Section I. GENERAL

2–1. General

The mission of field artillery battalion survey personnel is to provide timely survey control, executed within prescribed accuracies, to the required installations within the battalion. This consists primarily of that work necessary to determine the location, both horizontally and vertically, of the weapons and the targets. Accurate survey permits the construction of surveyed firing charts which are used to determine initial firing data and for the transfer of target data. In addition, field artillery survey must provide a means of orienting weapons, instruments and electronic equipment. Accomplishment of the battalion survey mission provides a common grid for firing units and target-locating installations. Provision of such a grid allows the field artillery to accomplish the following:

a. Massing of Fires. Accurate survey permits rapid and economical massing of fires. For artillery to mass fires accurately without survey requires an observed adjustment of all units on the target or prior registration of all units on a common registration point.

b. Delivery of Surprise Observed Fire. If survey is not available and all batteries are required to adjust on a target, the element of surprise is lost. Complete surprise cannot be obtained without survey.

c. Delivery of Effective Unobserved Fires. Without Survey, consistently effective unobserved fires can be accomplished only if the target has been previously fired on and replot data computed.

d. Transfer of Target Data Between Units. Transfer of target data between units is possible only when units are located relative to each other and to the target.

2–2. Survey Control Points on Grid of Next Higher Echelon

a. A battalion survey control point (BnSCP) is a point provided by a higher echelon of survey for the purpose of initiating survey control to the battalion. More than one such point may be provided for a battalion.

b. Survey control points on the grid of the next higher echelon may be available in the form of—

(1) One or more trig points in the vicinity of the battalion installations. When available, trig points should be used as the basis for battalion survey operations if survey control points have not been established for the battalion by the next higher echelon.

(2) One or more survey control points which have been established by the next higher echelon in the vicinity of the battalion installations. These survey control points should be used as the basis for battalion survey operations.

2–3. Divisions of Battalion Survey Operations

The various tasks required to complete a battalion survey are divided into three divisions of operations, as follows (fig 2–1):

a. Position Area Survey.

(1) For light, medium, and heavy field artillery—survey all battery centers. For rockets and missiles—survey each launcher.

(2) Establish orienting lines for each battery.

(3) Compute orienting angles as required.

(4) When required, establish survey control points (SCP) and perform necessary survey for countermortar radar and mortar platoons.

b. Target Area Survey.

(1) Establish and survey two or more observation posts (OP) for target area base.

(2) Survey critical points in the target area; i.e., registration and restitution points.

c. Connection Survey. Connect the target area survey to the position area survey thus placing both surveys on a common grid.

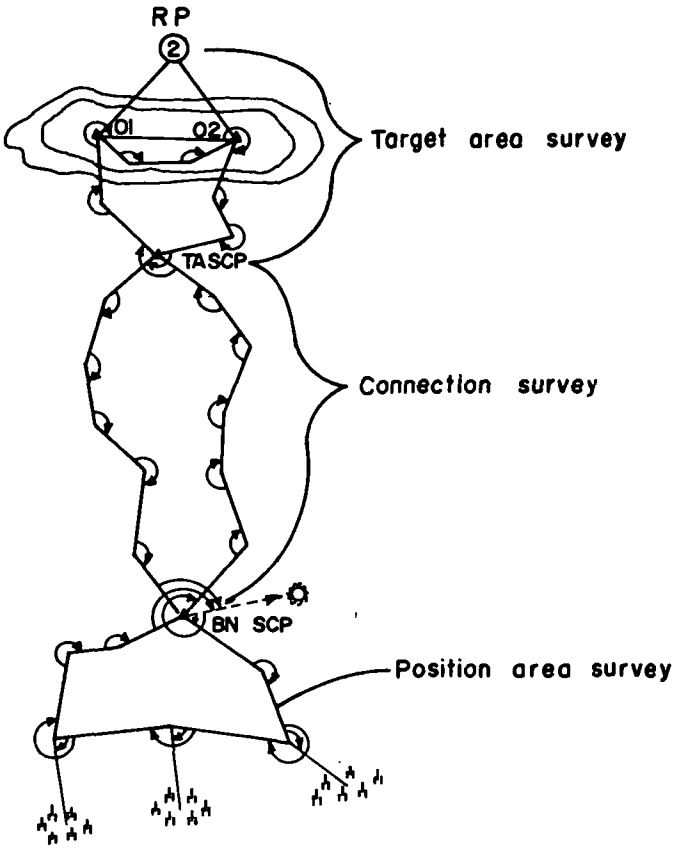


Figure 2-1. Three divisions of field artillery battalion survey.

2-4. Responsibility

The survey elements of the headquarters battery have the responsibility of performing the necessary surveys for the position and target area and the connection between the two. These surveys will be performed in accordance with the priorities established by the battalion commander. In a conventional, semistabilized situation where time is not a critical factor, it may be advantageous to make one of the fifth-order survey parties organic to headquarters battery, responsible for both the position area and target area surveys. A second survey party would then be responsible for performing the connection survey which ties together the position area and target areas, placing them on a common grid. In a general support field artillery battalion, a third party is normally authorized. It may be utilized as directed by the battalion survey officer. In other tactical situations however, such as one in which time is of the utmost importance or one where the target area is of reduced importance, it may be advantageous to utilize all survey parties to immediately complete the position area survey (by locating the firing batteries and the counter-mortar radar) if the survey is to be of maximum value to the firing elements. The batteries can then be registered by radar, if necessary, while the survey parties are conducting the target area and connection surveys.

2-5. Accuracies

a. Three minimum accuracies serve as standards for the field work and computations in field artillery survey. These accuracies are artillery fourth order (1:3,000), artillery fifth order (1:1,000), and 1:500. Accuracies expressed as fractions with a numerator of 1 mean that for the total units expressed in the denominator, the allowable error is one similar unit. For example, in a survey performed to fifth-order accuracy the maximum allowable error is 1 meter for every 1,000 meters surveyed.

b. Artillery fourth-order accuracy is used as the standard for surveys performed at division artillery and by the target acquisition battalion at corps artillery, whereas artillery fifth-order accuracy is the standard used for most field artillery battalion surveys. An accuracy standard of 1:500 is used only when the aiming circle is used in field artillery survey operations.

2-6. Variations in Starting Control

Starting control for field artillery survey consists of the coordinates and the height of a survey control point (SCP) and a starting azimuth. Although there are several ways in which starting control may be obtained, the best control available for the area should be used to begin a survey. The different variations of starting control can be grouped into three general categories, as follows:

a. Known Coordinates, Height and Azimuth. Starting control for which the station data are known may be points established by survey performed by higher echelon, or it may be confirmed data established prior to the start of military operations. The data for stations established by engineer topographic units and the data for survey control established prior to the start of military operations are contained in trig lists prepared and published by the Corps of Engineers. Survey data for survey stations established by the survey parties of the target acquisition battalions and division artilleries are published in trig lists prepared in their survey information centers and made available to all using units in the area.

b. Assumed Coordinates, Height and Correct Grid Azimuth. When survey control is not availa-

ble in the area, it is necessary to assume the coordinates and height of the starting station. The assumed data should approximate the correct coordinates and height as closely as possible to facilitate operations. If a map is available, the approximate coordinates can be scaled from the map. Any data scaled from a map is considered as assumed data. A correct starting grid azimuth should always be used whenever possible. If both higher and lower survey echelons are established with a correct grid azimuth and assumed coordinates, the difference in the location of points by the surveys will be constant and equal to the difference in the starting coordinates (chap 16).

c. *Assumed Coordinates, Height and Azimuth.* The starting azimuth for survey should be assumed only when it is not possible to use astronomic observations or the gyro azimuth surveying instrument to establish the correct grid azimuth. When it is necessary to use an assumed azimuth, it should approximate the correct grid azimuth, as closely as possible. The approximate grid azimuth can be established by using a declinated aiming circle or by scaling from a map. If either (or both) higher or lower echelon survey operations are started with an assumed azimuth, differences of varying magnitude will exist between the coordinates of points located by their surveys. For this reason, an assumed azimuth should never be used if it can possibly be avoided (chap 16).

2–7. Converting to Grid of Next Higher Echelon

a. The methods of converting survey data are described in chapter 16. Unless the tactical situation causes the commander to decide otherwise, battalion (battery) data are converted to the data of the next higher echelon when data differs by—

(1) Two mils or more in azimuth, or
(2) Ten meters or more in radial error, or
(3) Two meters or more in height.

b. If the next higher echelon converts its survey control to a different grid, the battalion must also convert to that grid.

c. The problem of converting data to a common grid is greatly simplified if survey personnel use the correct grid azimuth to initiate survey operations. True azimuth can be obtained from astronomic observations or by use of the azimuth gyro. The true azimuth can then be converted to grid azimuth by applying grid convergence.

Section II. POSITION AREA SURVEY

2–8. Position Area Survey Requirements

Survey control is required in the position area of each firing battery of the field artillery battalions and at each launcher position of the rocket and missile battalions. Survey is accomplished by the headquarters battery survey section. Light, medium, and heavy artillery battery position area survey requirements are identical. The requirements of missile and rocket units vary slightly due to system design and development (para 2–21 through 2–24). A typical position area survey required for a direct support battalion is indicated in figure 2–2.

a. Battalion and Battery Survey Control Points. Survey control for artillery units may be available in the form of (1) trig lists containing data for stations located in the vicinity of (2) survey control points established by higher echelon. When possible, the survey control point should be established to a fourth-order accuracy. As a general rule, survey control should be established by division artillery within 1500–2000 meters of the firing positions of the battalion. If the firing elements of the battalion are widely dispersed, it may be necessary to establish more than one survey control point for the battalion. If no survey control points exist in the area in which the battalion is employed, the reconnaissance and survey officer of the battalion will select a convenient point in the battalion area and determine the best possible data (coordinates, height, and direction) for starting the survey. When batteries are operating separately from the battalion, it is usually necessary to establish a battery survey control point and perform a separate position area survey.

b. Battery Centers. For light, medium, and heavy field artillery, the approximate geometric center of the weapons position is established as the battery center and is located by survey. For rockets and missiles, each launcher position is located by survey. Normally, the battery center or weapons position is selected by the battery commander or executive officer.

c. Orienting Line. An orienting line (OL) is a line of known direction materialized on the ground in each position area. It is used as a reference direction for orienting instruments and for laying weapons for direction. The orienting line should

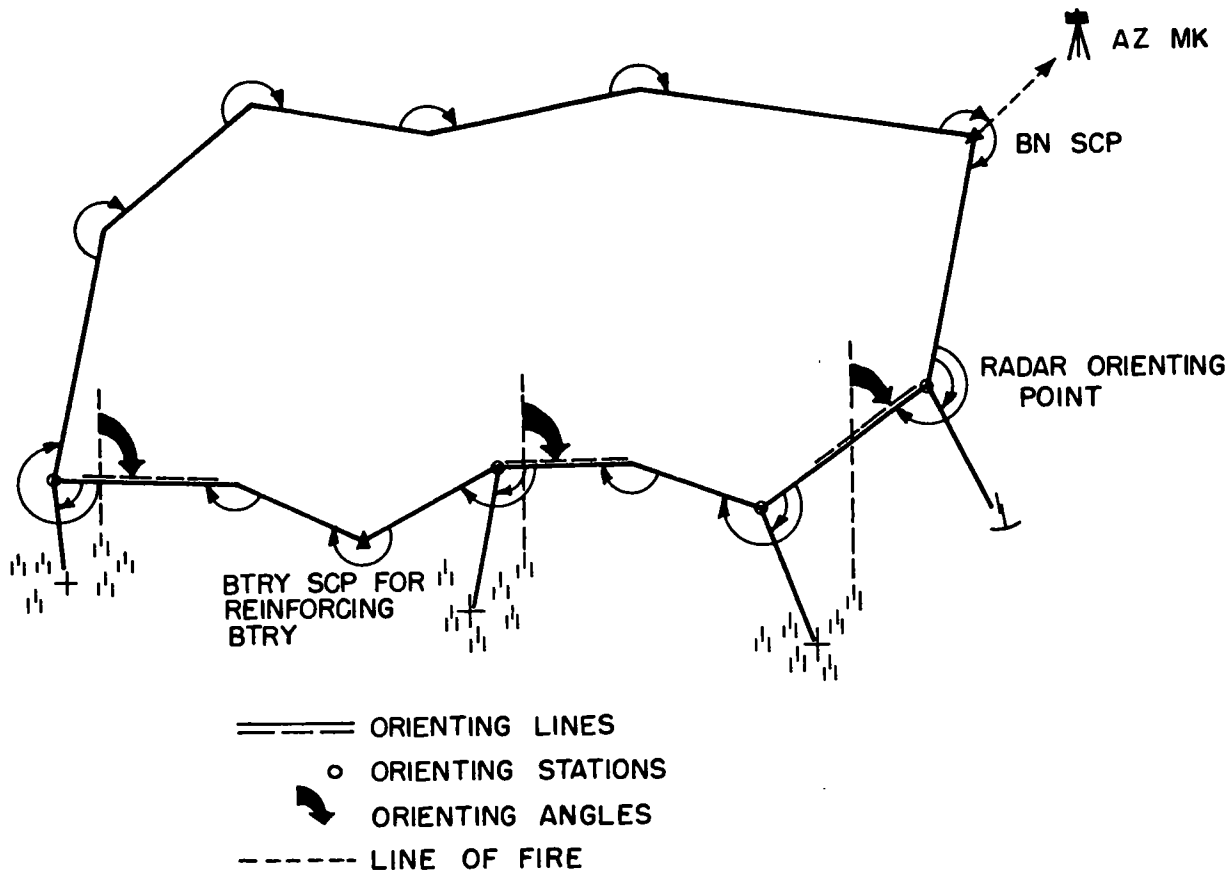


Figure 2–2. Schematic drawing of a direct support battalion position area survey.

be a leg (closest to the start of the survey) in the position area traverse so that a check on the accuracy of the orienting line is obtained when the survey is closed.

d. Orienting Station. The orienting station (OS) is a station on the orienting line used by the battery executive officer to orient his instrument for laying the weapon(s). Normally, the orienting station will be established on one end of the orienting line. The position of the orienting station usually is selected by the battery commander or executive officer and is included as a traverse station in the position area survey.

e. Orienting Angle. The orienting angle is the horizontal, clockwise angle for the line of fire to the orienting line. When the orienting angle is set on the scales of the executive officer's aiming circle and used in conjunction with the orienting line, it facilitates orienting the weapons of the battery on common directional control. Figure 2–3 and the example which follows illustrates the procedure for computing an orienting angle.

Example:
Azimuth of line of fire = 200 mils
Azimuth of orienting line = 1,400 mils

Solution:
1,400 mils = azimuth of orienting line
—200 mils = azimuth of line of fire
1,200 mils = orienting angle

f. Radar. One countermortar radar (AN/MPQ–4A) section is organic to each direct support howitzer battalion. The coordinates and the

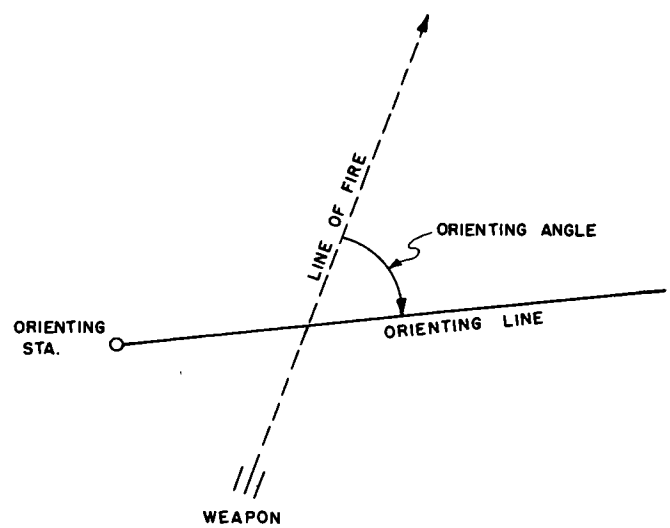


Figure 2–3. Schematic drawing illustrating orienting angle.

height of the radar position and a line of known direction are required. The determination of these data is the responsibility of the headquarters battery survey section. Normally, the division artillery surveillance radar (AN/TPS–25) will be located near one of the artillery battalions, and division artillery will usually require its nearest organic or attached battalion to provide the necessary survey control. The height of the radar antenna must also be computed. This radar has a unique survey requirement in that it requires distance and direction to reference points. Height is determined by measuring the distance from the ground to the antenna, to the nearest 0.1 meter. The distance measured is added to the computed ground height for the radar site.

g. Line of Fire. A base direction of fire for all weapons of the firing unit. It may be the computed azimuth from the battery center to the registration point or a selected azimuth of fire assigned to the unit by the battalion commander or other authority.

2–15. Method of Preforming Target Area Survey

a. Any method or combination of survey methods may be used to perform the position area survey; however, the method most commonly used is traverse. The position area survey is initiated at a survey control point (the point that establishes the unit grid), moves to its destination and terminates on the starting point or on a station established to an accuracy equal to or greater than that of the survey being performed. All survey for performing Position Area requirements is executed to fifth order.

b. In surveying a battery position, an orienting station, from which all battery weapons should be visible, is established near the battery center. Normally, this point is used as one end of the orienting line, and the traverse leg used to establish the station is used as the orienting line. This makes the orienting line a leg of the closed traverse, thus permitting the detection of an error in the OL should the traverse not close in azimuth. If a traverse leg cannot be used as the orienting line, a prominent terrain object at least 300 meters away should be used as the end of the OL. The azimuth of this line is determined by measuring, at the orienting station, the angle from the rear (last) traverse station to the selected point. Two positions should be turned to the selected point. For night operations, the orienting line must be prepared for orientation of the weapons by placing a stake equipped with a night lighting device on the orienting line approximately 100 meters from the orienting station. When an intermediate point cannot be established on the orienting line, an alternate orienting line is established on which the night orienting point can be set up.

c. The coordinates and height of the battery center are determined by establishing a traverse station over the battery center or by establishing an offset leg (an open traverse leg) from the orienting station to the battery center.

2–10. Survey of Alternate Positions

Survey operations for alternate positions should be performed as soon as survey operations are completed for primary positions. The requirements for alternate positions are identical with the requirements for primary positions.

Section III. CONNECTION SURVEY

2–11. General

a. Connection survey is that part of the survey operation performed by battalion (separate battery) survey personnel for the purpose of placing the target area survey and the position area survey on a common grid (fig 2–4).

b. Connection surveys are executed to fifth-order accuracy.

2–12. Methods of Performing Connection Survey

a. A closed traverse normally is used to perform the connection survey, although other methods of survey may be used when the terrain or weather conditions make it unsuitable for traverse. The connection survey is used to establish a target area survey control point or one or more of the target area base observation posts from which target area base survey operations are initiated. The connection survey is usually initiated at a station of the position area survey. The station may be a Bn SCP or the point which establishes the battalion grid. When the connection survey is initiated at a Bn SCP, it may close on that SCP or on any other SCP established to an accuracy of 1:1,000 or greater on the same grid as the Bn SCP. When the connection survey is initiated at

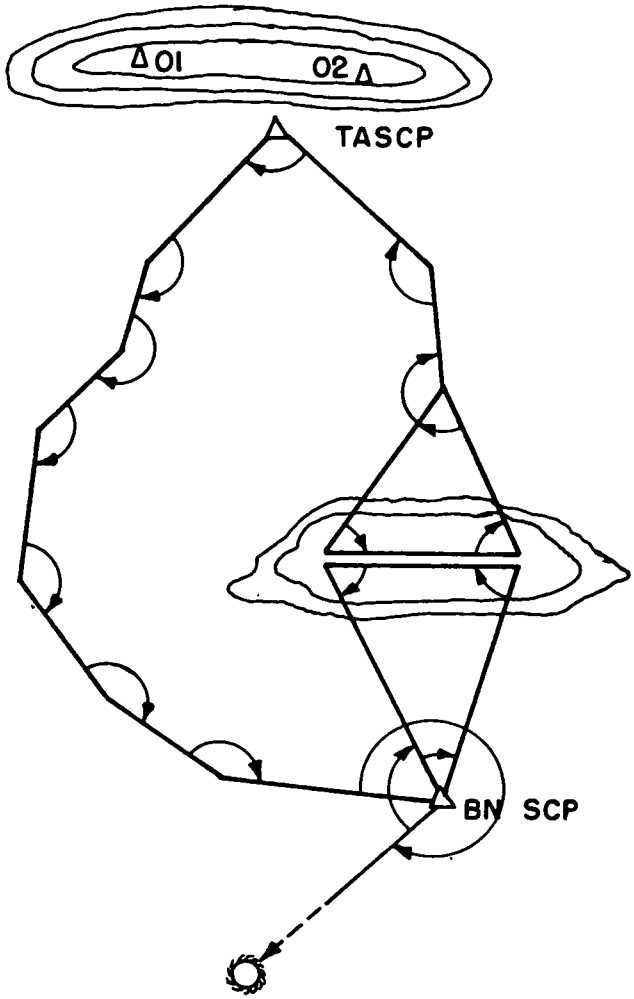


Figure 2–4. Schematic illustration of connection survey.

the point that establishes the battalion grid (i.e., when data for the starting point is assumed), it must close on the starting point. This point does not become the Bn SCP unless survey control for the point is established by the next higher echelon of survey.

b. A secondary requirement for connection survey may include providing control for the mortars within the supported brigade or for radars and other target acquisition devices located within the area of operation. Control is extended to these installations as time permits. The requirements of the field artillery battalion take priority in these instances.

c. Since missile units normally are employed in a general support or reinforcing role, they normally receive target data from higher headquarters or the supported unit. Therefore, these units do not perform target area or connection survey.

Section IV. TARGET AREA SURVEY

2–13. General

The survey mission in the target area is to establish a target area base composed of two or more observation posts, and by the use of the base to extend common control to critical points such as registration points and restitution points, in the target area. The target area base is also used in mean-point-of-impact and high-burst registrations and in locating targets of opportunity. Target area survey is normally performed by one of the fifth-order parties of the battalion survey section. When the target area base is established, the survey parties are modified to form observing teams, composed of one observer and one radio-telephone operator per team. One team will be assigned to each of the observation posts.

2–14. Methods of Preforming Target Area Base Survey

a. A prerequisite for accomplishing the target area mission is the establishment of a base from which the targets and critical points may be surveyed. The requirements for establishing a target area base are to locate two or more observation posts relative to each other which overlook the target area, to determine the azimuth and distance between the two, and to determine an azimuth to a visible azimuth mark for each. The observation posts are designated 01, 02, etc. 01 is considered the control OP and is plotted on the firing chart. 01 may be on the right or on the left of the base, but is always that OP requiring the least amount of field work to establish its location since less directional accuracy is lost through angular meas-

urements when the number of main schemes angles is held to a minimum (i.e., if the OP on the left can be established in two traverse legs from the target area survey control point and five traverse legs are required to establish the OP on the right, then the OP on the left would be designated as 01) (fig 2–5).

b. In selecting observation posts, if possible, the distance between any two OP's should be sufficient to insure an apex angle of 300 mils at any of the critical points. If this is not possible, then the two OPs must be far enough apart to insure, at the very minimum, an angle of 150 mils at any critical point in the target area (fig 2–6). The consistent accuracy that can be obtained from the location of points with angles of the minimum size is approximately 1 :200.

c. An azimuth mark for each observation post must be selected and the azimuth to each determined. In addition to the azimuth mark a reference stake should be placed on the same azimuth for each observation post to be used for night orientation. If 01 and 02 are intervisible, each can use the opposite observation post as an azimuth mark. If the two OPs are not intervisible, a separate azimuth mark (i.e.. usually prominent terrain features or immovable, well-defined objects) must be selected in the approximate center of the sector of observation.

d. The methods of survey normally used by the survey party in establishing the target area base are a closed traverse, triangulation, or when control is available, resection. In establishing the target area base, all members of the survey party must execute extreme caution because of the distinctive silhouette made by the instrument and/or party personnel on the skyline. Triangulation is used when the terrain allows or when the enemy

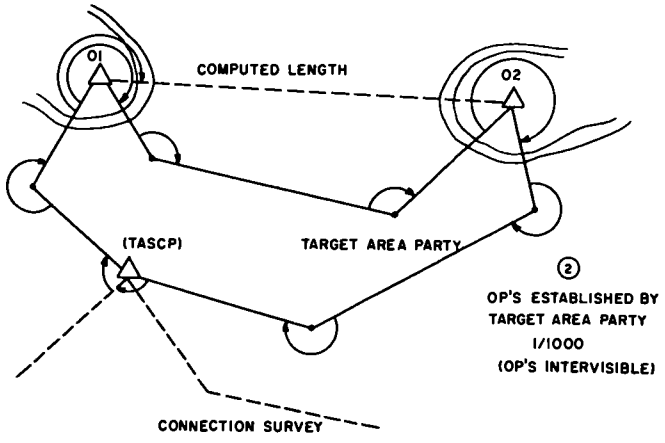


Figure 2–5. Target area base survey.

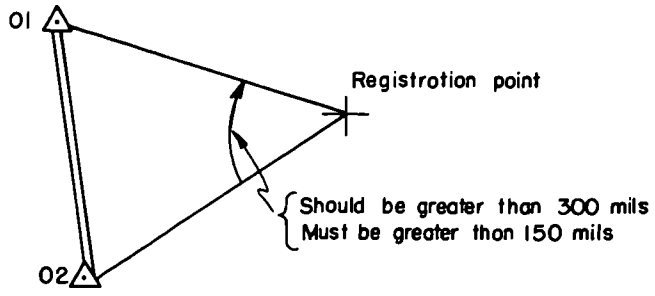


Figure 2–6. Minimum apex angles.

situation so warrants. On other occasions, the methods used may be either intersection or offset from a traverse or triangulation station in the vicinity of each observation post. When the observation posts are intervisible, the azimuth of the base is determined by measuring at 01 the horizontal, clockwise angle from a rear station, to 02. The base length is determined by computation from coordinates of 01 and 02, or by taping, if the tactical situation so warrants. When observation posts are nonintervisible, the azimuth and distance of the base are determined by computation, using the coordinates of 01 and 02 as previously determined. Observation posts are located using fifth-order survey procedures.

2–15. Method of Performing Target Area Survey

The fieldwork, from the target area base, consists of surveying all designated critical points (i.e., registration and restitution points, app D) in the target area. Surveying of the critical points is accomplished by the personnel designated to occupy the observation posts. The method of survey used for determining the location of the critical points from the two OP's forming the base is intersection. Intersection differs from triangulation in that the angle at the target is not measured, but is computed. The instrument normally

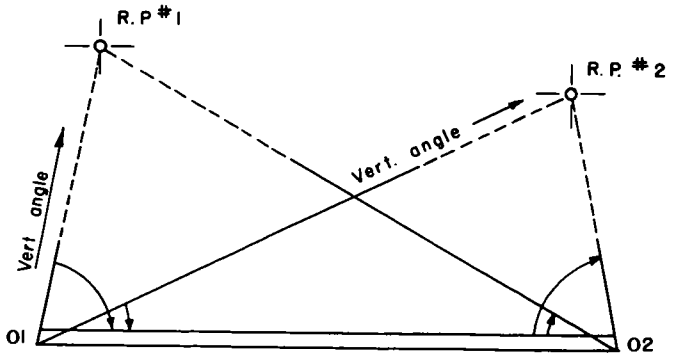


Figure 2–7. Angular measurements-observation posts intervisible.

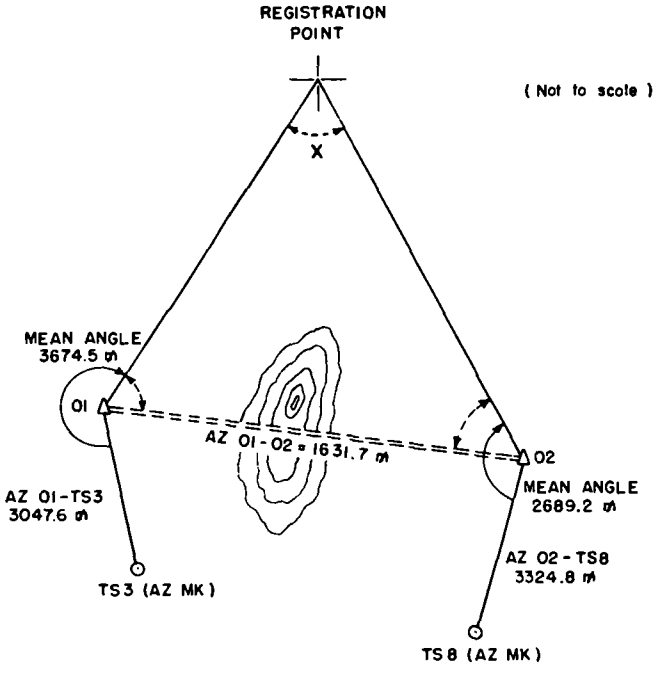


Figure 8. Exampla problem -- observation posts not intervisible.

Requirement : Determine velues of interior angles of the 01 - reg pt - 02 triengle (fig 8).

Solution : Interior angle, reg pt - 01 - 02

	Az 01 - TS 3	3,047. 6 mils
∢	TS 3 - 01 - reg pt	3,674. 5 mils
	Az 01 - reg pt	6,722. 1 mils
	Az 01 - reg pt	(–) 6,400. 0 mils
		322. 1 mils
	Az 01 - 02	1,631. 7 mils
(–)	Az 01 - reg pt	322. 1 mils
	Interior ∢ at 01	1,309. 6 mils

Interior engle et 02

	Az 02 - TS 8	3,324. 8 mils
∢	TS 8 - 02 - reg pt	2,689. 2 mils
	Az 02 - reg pt	6,014. 0 mils
	Az 01 - 02	1,631. 7 mils
		(+) 3,200. 0 mils
	Az 02 - 01	4,831. 7 mils
	Az 02 - reg pt	6,014. 0 mils
	Az 02 - 01	4,831. 7 mils
	Interior ∢ at 02	1,182. 3 mils

Interior engle at reg pt

X = value of interior angle et reg pt

X = 3,200. 0 mils - (1,309. 6 mils + 1,182. 3 mils)

X = 3,200. 0 mils - 2,491. 9 mils

X = 708. 1 mils

Figure 2-8. Example problem-observation posts not intervisible.

used on the base is the aiming circle. However, when greater accuracies are required, the 0.2 mil theodolite may be used.

a. When the OPs of the target area base are intervisible, the interior angles of the triangle at each OP are measured two repetitions to determine the mean horizontal angle (fig 2–7). These two angles are added and the sum is then subtracted from 3,200 mils to determine the value of the interior angle at the apex of the triangle. Since 01 is the more accurate of the two observation posts, a vertical angle is measured two repetitions from 01 to the lowest visible point on the target. These two readings are meaned to determine the mean vertical angle between 01 and the target (fig. 2–7). With the values of the three interior angles of the triangle, the length and azimuth of the base, vertical angle from 01 to the registration point, and the coordinates and height of 01, the coordinates and the height of the registration point can be determined.

b. When the OP's of the target area base are not intervisible, the interior angles of the triangle must be determined by comparing the azimuth of the base with the azimuth from each observation post to the critical point being located (fig 2–8). The azimuth from each observation post to the critical point in the target area is determined by sighting the survey instrument on the azimuth mark provided and measuring the horizontal clockwise angle to the critical point. The value of this angle is added to the azimuth of the azimuth mark and the sum is the azimuth from the OP to the point in the target area. With the values of the three interior angles, length of base, vertical angle and azimuth 01 to registration point and coordinates of 01, the coordinates and height of the critical point can be computed. The party performing the target area survey furnishes the location of the registration point(s) to the party performing the position area survey for computation of the orienting angle(s). The location of critical points determined from the target area base should be checked by the establishment of a second intersection base. A second base can be established by using a third observation post and either of the two initial observation posts.

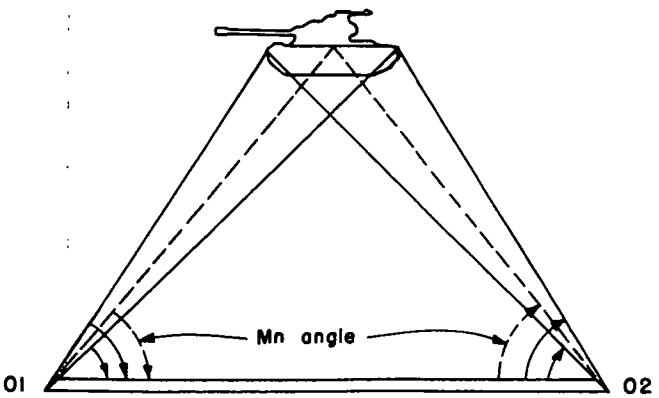


Figure 2–9. Special pointing technique.

2–16. Special Pointing Techniques

In those cases where the critical point does not present a clearly defined aiming point (i.e., critical point is a disabled tank, etc.) and cannot be accurately bisected, angles are measured first to the left edge and then to the right edge of the object accumulating these angles on the aiming circle. The angles are then meaned. This comprises one set of pointings; a second set is made to verify the mean. The means from both sets of pointings are then remeaned to determine the angular value. This will provide a mean angle to the approximate center of the object to the nearest 0.1 mil. Vertical angles in this case are still measured to the lowest visible point on the object (fig 2–9).

2–17. Application to Targets of Opportunity

Once the target area base has been established and critical points have been surveyed, the survey personnel occupying each observation post will concern themselves with locating targets of opportunity. Instruments are oriented on the azimuth marks which were previously selected. When this has been accomplished, any pointing of the aiming circle using the upper motion will record the direction in which the telescope is pointed. When a target of opportunity appears, both observation posts will sight their instruments on the target and read the azimuth to the target. Interior angles at each observation post can then be determined directly by a comparison of the azimuth from that observation post to the target with the azimuth of the base. Observation post 01 will normally transmit its azimuth reading to 01, and survey personnel occupying 01 will rapidly compute (using logarithms or the military slide rule) an 01-target distance. The fire mission will be transmitted to the fire direction center (FDC) by using the polar plot method.

Note. Targets of opportunity are located by means of single azimuth readings from each observation post to the target. The primary consideration in surveying targets of opportunity is a *rapid* transmission of target data to the fire direction center.

2–18. Accuracies for Locating Critical Points

a. For heavy artillery units (and for long-range interdiction and destruction missions), the desired accuracy for locating critical points is fifth-order.

For medium and light artillery units, the desired accuracy for locating critical points is 1:500.

b. When observation posts (OP's) are occupied with aiming circles and the distances between the OP's are sufficient to insure an apex angle of 300 mils at any of the critical points, the accuracy to which those critical points will be located is 1:500. Regardless of the base accuracy, the location of critical points determined from the target area survey should be checked by an intersection from another base. This base may be established with an additional observation post in conjunction with one of the existing observation posts. Under some circumstances, a quick check of any intersected point can be executed by coordination with the target area base of an adjacent battalion.

2–19. Application to High-Burst and Mean-Point-of-Impact Registrations

In either a mean-point-of-impact or high-burst registration, a group of rounds is fired into the center of the area to which gunnery corrections are to apply. In order that it may be accurately plotted on the firing chart, the location of the burst center must be determined. One method commonly used to accomplish this is computed intersection from the 01–02 target area base. This method requires that the bursts be observed by both 01 and 02; therefore, primary consideration must be given to the topography of the impact area and the location of each observation post. For a high-burst registration, which is conducted with a time fuze and rounds burst in the air, these considerations are normally of lesser importance than for a mean-point-of-impact registration. For a mean-point-of-impact registration employing an impact fuze, the burst area should be free of trees, buildings, sharp ravines, etc. A prominent feature such as a large rock, a lone tree, or a trail junction located on a gentle forward slope is ideal. In conducting a mean-point-of-impact or high-burst registration, the location of each observer and the desired point of burst are known at the fire direction center. The fire direction center will determine and furnish to each observer the direction and vertical angle to the expected point of burst. The message to the observers from the fire direction center will include instructions to 01 to measure the vertical angle to each burst. A typical message to the observers from the fire direction center is as follows: "Observe high burst (or mean point of impact). 01 direction 1049, vertical angle + 15; measure the vertical angle. 02 direction 768, vertical angle +12. Report when ready to observe." The observers at 01 and 02 orient their observing instruments on the direction and vertical angle given for each observation post and report when ready to observe. One round at a time is fired, and "shot" is given to the observers for each round. The first round fired is normally an orienting round, and each observer will orient the center of the reticle of his instrument on the burst and note the scale readings of his instrument corresponding to the new position of the telescope. After the orienting round, the observer should not have to change the orientation of his instrument for the rest of the registration. One round at a time is fired until six usable rounds have been fired (eliminating erratic rounds and rounds observed by only one observer). After the orienting rounds, the deviation observed on the reticle to each burst is combined with the reference reading on the instrument scales to derive the direction to the burst. The same general procedure is used to measure the vertical angle. Both observers report direction readings to the fire direction center after each round, but only the observer at 01 will report the vertical angle. At the fire direction center, the instrument readings from 01 and 02 for the six usable rounds are used to determine the mean point of impact for the registration.

2–20. Computation of Mean-Point-of-Impact and High-Burst

The target area base may be used as a tool in performing a mean-point-of-impact or high-burst registration. Normally the computations associated with the instrument readings to determine the location of the mean-point-of-impact or high-burst are performed by the fire direction personnel. A knowledge of the manner in which these computations are performed is of value to the survey personnel operating the target area base. The computations normally are made on DA Form 6–55 (High Burst (Center of Impact) Registration).

Example:

Given:	Coordinates of 01:	(561599.8–3839123.3)
	Aximuth 01 to 02:	3,960 mils
	Distance 01 to 02:	843 meters
	Height 01:	453 meters

Instrument readings of usable rounds:

Round	Azimuth 01 (mils)	Vertical ½ 01 (mils)	Azimuth 02 (mils)
1	5,170	+24	5,959
2	5,710	+28	5,950
3	5,708	+29	5,953
4	5,705	+25	5,951
5	5,715	+23	5,952
6	5,713	+26	5,955

Requirement: Solve for the azimuth and distance from 01 to center of the high burst and the height of the high burst, using DA Form 6–55 (fig 2–10).

HIGH BURST *(CENTER OF IMPACT)* REGISTRATION
(FM 6-40)

COMPUTATION OF HB (CI) LOCATION

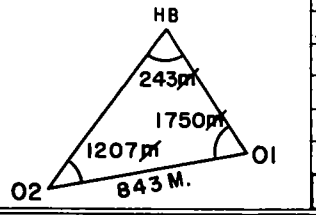
Date Fired	Chg	Df	FS	QE

Observer Readings

Rd Nr	O1 Az	VA	O2 Az
1	5710	24	5959
2	5710	28	5950
3	5708	29	5953
4	5705	25	5951
5	5715	23	5952
6	5713	26	5955
7			
8			
9			
10			
	34261	155	35720
	5710	26	5953

Inferior Angles

O1 on Left		O1 on Right	
Az O1→O2		Az O1→HB ~~(CI)~~	5710
+6400 if necessary		+6400 if necessary	—
Total		Total	5710
−Az O1→HB (CI)		−Az O1→O2	3960
∠ at O1		∠ at O1	1750
Az O2→HB (CI)		Az O2→O1	760
+6400 if necessary		+6400 if necessary	6400
Total		Total	7160
−Az O2→O1		−Az O2→HB (CI)	5953
∠ at O2		∠ at O2	1207



Apex Angle	
∠ at O1	1750
+∠ at O2	1207
Sum	2957
	3200
−Sum	2957
Apex Angle	243

Bearing = 6400 − Az (dE−, dN+) Bearing = Az (dE+, dN+)
Bearing = Az − 3200 (dE−, dN−) Bearing = 3200 − Az (dE+, dN−)

Az O1→HB→ Bearing
6400
5710
Bearing
690 mil

Distance O1 HB (CI)			
Log base O1→O2	843 M.	2 925	828
+Log sin ∠ at O2	1207 mil	9 966	840
Sum		2 892	668
−Log sin Apex Angle	243 mil	9 373	479
diff = Log dist O1→HB(CI)		3 519	189
Dist O1→HB ~~(CI)~~*		3305.1 M	

Log conversion factor, meters to yards odd 0.038863

*Determine the distance O1—HB (CI) to check computations of dE, dN & dH by polar plotting from O1 on average azimuth and computed dist

Log of dE, dN, and dH

Log dist O1→HB(CI)	3 519 189	Log dist O1→HB(CI)	3 519 189	Log dist O1→HB(CI)	3 519 189
Log sin Bearing	9 797 111	Log cos Bearing	9 891 650	Log Tan Vert ∠	8 407 068
Sum= Log dE	3 316 300	Sum= Log DN	3 410 839	Sum= Log dH	1 926 257

Coordinates of O1	E	561 599.8	N	3 839 123.3	H		453.0
	±dE	2071.6	+dN	2575.4	+dH		84.4
Location of HB (CI)	E	559 528.2	N	3 841 698.7	H		537.4

COMPUTATION OF GFT SETTING

Alt HB(CI)		QE fired		Chart data to HB (CI) location	Df corr
−Alt Btry		−Site		Deflection ____ of Range ____ M	
VI		VI/HB(CI) Rg		GFT ____ " Charge ____ Lot ____	
		Adj Elev		Range ____ Elevation ____ Time ____	
				(HB or CI Rg) (Ti fired)	

DA FORM 1 OCT 60 6-55

* U.S. GOVERNMENT PRINTING OFFICE : 1960 O—573453

Figure 2–10. High burst registration, DA Form 6–55.

Section V. MISSILE BATTALION SURVEY

2–21. General

Missile units generally are concerned with position area survey only. Each system has individual and peculiar requirements that vary slightly from other field artillery units due to equipment design, difference in number of launchers, and auxiliary equipment requiring survey control. Numerous alternate position areas are essential for survival, and all require the same survey as the primary position area.

2–22. Honest John

a. The field artillery battalion, Honest John, is organic to the infantry, armored, and mechanized divisions and is also normally assigned to corps artillery as a separate battalion. Its mission is to provide long-range artillery general support and/or reinforcing fires. The divisional battalions are organized with two firing batteries of two launchers each. The separate battalions have three firing batteries of two launchers each. In both types of battalions, the survey personnel are assigned to headquarters and headquarters battery. The divisional battalion is authorized a chief surveyor and two parties equipped with 0.2-mil theodolites. The separate battalion is authorized three parties each equipped with gyroscopic orientors and 0.2-mil theodolites. These personnel operate under the supervision of the battalion reconnaissance and survey officer.

b. The Honest John free-flight rocket is fired from a launcher rail which is laid for direction by conventional artillery means. The survey requirements are identical with those for heavy artillery except that additional survey is required for the windset. Each launcher requires a fifth-order location and an orienting line accurate to 1 mil. The rocket, which has large tail fins, is seriously affected by low-level winds. A windset is provided to measure the surface winds so that a correction may be applied. This windset must be oriented in direction, thus establishing a second need for an orienting line in the position area. Normally, the orienting line provided for the launcher will also suffice for the windset, but, in some circumstances, separate orienting stations and lines must be established.

2–23. Sergeant

a. The field artillery battalion, Sergeant, normally is assigned in general support of a corps or army. The battalion consists of a headquarters, headquarters and service battery and two firing batteries with one launcher each. The headquarters battery is authorized two Distance Measuring Equipment (DME) equipped parties and each firing battery is authorized one survey party equipped with the 0.002-mil theodolite. Each firing battery is authorized a reconnaissance and survey officer, who operates under the staff supervision of the battalion reconnaissance and survey officer.

b. The Sergeant employs an inertial guidance system that operates on information or errors sensed by accelerometers and potentiometers. The accelerometers are mounted on a stabilized platform which is kept in proper orientation by gyroscopes. The present position of the missile is compared with a predetermined reference trajectory. The angular position of the missile, about its center of gravity, produces an error in the relationship of the missile frame to the stabilized platform. The guidance system is completely self-contained on board the missile and depends on no other information than that of errors generated in flight. These errors are converted to corrections, which eventually position the control surfaces as required to reposition the missile. Since all path control information is determined by devices within the missile and slight errors are magnified by the long ranges involved, a precise degree of alinement of the stabilized platform on the firing azimuth is necessary. The stable platform is oriented by an azimuth orientation unit (AOU), a modified 0.002-mil theodolite mounted on the launcher. The launcher is laid reciprocally by a reference theodolite with respect to a surveyed orienting line.

c. Survey requirements for the Sergeant include the position location of the launcher to fifth-order accuracy and an orienting line accurate to ± 0.3 mil. As with all missile systems that are provided targets by outside agencies, all survey data must be started from common control or be converted to the common grid immediately.

d. The target acquisition battalion normally establishes a survey control point (fourth order) with an accuracy in direction of ± 0.15 mil within 1,000 meters of each battery position area. The ± 0.3 mil requirement for the orienting line can be satisfied by traverse from this survey control point providing that no more than seven station angles are used to carry direction from the SCP to

either end of the orienting line and that each angle is turned two positions with a ± 0.02 mil rejection limit, or, fourth-order astronomic or gyroscopic means may be used at the orienting station to put azimuth on the orienting line. Each launcher position should be established to fifth order accuracy but a grid map spot will suffice.

2–24. Pershing

a. The field artillery battalion, Pershing provides nuclear fires in special employment or in general support (GS) of a field army or an independent corps. The battalion is allocated as required for special employment of one per field army or independent corps. The battalion is organized with a headquarters and headquarters battery, a service battery, and four firing batteries. The battalion reconnaissance and survey officer is located in the headquarters and is a member of the battalion commander's staff. A survey information center, consisting of a chief surveyor and three men, is assigned to headquarters battery; its primary function is to collect and maintain records on survey control.

b. Survey control for the Pershing battalion normally will be provided within 1,000 meters of each firing position by an engineer topographic battalion. This control will consist of the coordinates and height of the survey control point, established to fourth-order accuracy (1:3,000) and an azimuth to an azimuth mark established to a third-order astronomic accuracy (plus or minus 5 seconds or 0.025 mil). The unit survey party performs a closed survey from this survey control point to determine the—

(1) Grid coordinates and height of the location of each launcher to a fifth-order accuracy (1:1,000).

(2) Grid azimuth of an orienting line to an accuracy of plus or minus 0.1 mil.

c. When survey control that meets the azimuth accuracy requirement is available, direction may be extended to the orienting line as a part of the position area survey, providing no more than two intermediate stations are required to establish the orienting station, and the leg from the second intermediate station, to the orienting station is the orienting line. In carrying azimuth to the orienting line, all angles are measured two positions. If the value of the angle determined from each position varies by more than 0.02 mil from the mean value of the two positions (i.e., if the spread exceeds 0.04 mil) both measurements are voided and the angle is remeasured. This procedure will insure an accuracy of 0.1 mil. When more than two intermediate stations are required to establish location to an accuracy of 1:1,000, a directional traverse, using no more than two intermediate stations, is used to determine azimuth of the orienting line. This azimuth should be checked by astronomic or gyroscopic means whenever possible. When astronomic or gyroscopic means are used, observations are made at the orienting station with the azimuth mark being the end of the orienting line.

d. The following specifications for astronomic observations must be adhered to in order to obtain the prescribed azimuth accuracy:

(1) *Horizontal and vertical angles.* Four sets of observations are required. In each set, the horizontal angles are measured one position; the vertical angels are measured, one direct (D) and one reverse (R).

(2) *Rejection limits.* Azimuths are computed from the four sets of observations. Any computed azimuth which does not agree with the mean of the four sets by less than plus or minus 0.1 mil is rejected. The final mean azimuth must be determined from at least 3 usable azimuths. For gyro azimuth surveying instrument observations, see paragraph 15–7.

e. When directional control of the required accuracy is not available within 1,000 meters of the firing position, the azimuth of the orienting line may be determined by using simultaneous observations. The use of this method requires a line of known direction (third order astronomic accuracy) within a radius of 26,000 meters of the firing position. One end of the line is used as the master station. The orienting station is designated as the flank station and the observations are performed as described in paragraphs 14–64 through 14–66. The azimuth mark for the flank station is one end of the orienting line.

CHAPTER 3
HIGHER ECHELON SURVEYS

Section I. DIVISION SURVEY OPERATIONS

3–1. General

The survey mission of division artillery is to perform those survey operations necessary to place organic, assigned, or attached field artillery units on a common grid. This mission is accomplished through fieldwork, coordination, and the timely collection, evaluation, and dissemination of survey information. When division artillery is operating as part of a corps, the common grid on which the division artillery units operate should be the corps artillery grid. If corps artillery control points are not available within the division area, the division artillery survey officer must select a starting point, assume survey control, and establish the division grid. Survey control is then extended from this point to within 1,500–2,000 meters of the using units. It is converted to the corps grid when corps artillery control becomes available.

Note. The accuracies for surveys performed by division artillery are the same as those of the target acquisition battalion at corps; i.e., a minimum prescribed accuracy of 1:3,000 (fourth order). Specifications and techniques required to produce this accuracy for the various methods of survey are specified in appendix B.

3–2. Division Artillery Reconnaissance and Survey Officer

The division artillery reconnaissance and survey officer is the principal adviser to the division artillery commander and his staff on survey matters. His principal duties are as follows:

a. Plans and supervises the division artillery survey operations and training. In planning the division artillery survey, he must coordinate with the S2 and S3 to insure that the plan provides for survey control to all elements of the division and the target acquisition platoons that require control. He maintains close coordination with the S3 on the planning of future operations so that survey planning for support may begin as soon as possible. He advises the S2 on the results of his reconnaissance concerning the status of existing roads, bridges and the terrain in those areas in which survey teams are operating.

b. Coordinates with assigned and attached field artillery battalions by keeping them informed of the status of existing survey control in their areas of operations. This is accomplished by frequent liaison trips to each battalion. The survey activities of assigned and attached units must be coordinated as soon as possible to prevent duplication of the survey effort. When available, the use of helicopters will expedite the entire division artillery survey effort.

c. Supervises the operations of the survey information center and its authorizel personnel.

d. Maintains continuous liaison with the corps artillery survey officer through personal liaison with the target acquisition battalion's survey officer and by the exchange of survey information between the survey information centers at division and corps level. Since target acquisition battalions perform survey in the division area, the coordination of their survey plans with those of division artillery is of benefit to both echelons.

3–3. Division Artillery Survey Information Center (SIC)

The purpose of the division artillery survey information center is to collect, evaluate and disseminate survey information to units of the division. This section has assigned, three enlisted personnel. The survey information center is normally located near the operations section (to facilitate communications), and it maintains a 24-hour operations. Personnel desiring survey information contact the survey information center direct.

a. A file of survey information is maintained in the SIC which includes trig lists covering actual and proposed areas of operation of the division artillery; a card index file, DA Form 3613

(Record of Survey (fig 3–1 Control Point) and 3–2) containing all fourth-order (1:3,000) and higher control points and designated fifth-order (1:1,000) survey control points established by division artillery battalions.

b. Survey Information Maps and Overlays are maintained by the survey information center to aid in the rapid dissemination of required survey information to using units and to aid the division artillery survey officer in planning the division artillery survey. These maps and overlays should show information as follows:

(1) Known survey control points.

(2) Proposed surveys, to include, when possible, surveys proposed by the battalions of the division.

(3) Completed surveys.

(4) Friendly and enemy situation when it is such that it might affect the planning or performance of survey in the division area.

(5) Present and proposed artillery positions in the division area.

c. The survey information center is responsible for performing the following computations and checks:

(1) Must check field records and computations of the division's survey parties. When survey is being executed, party personnel maintain a complete record of all fieldwork performed (field notebook) and all computations performed (DA Forms). On completion of a survey, the field notebook, together with the computations and results of the survey (closure), are forwarded or delivered to the survey information center for checking, adjusting and recording.

(2) Must adjust all fourth-order traverses, to distribute minor errors in distance and direction throughout all stations occupied in the survey. Prior to adjustment, all traverses must meet the minimum closure requirements.

(3) When required, must convert survey data to the corps grid by swinging and sliding operations.

(4) When required, must perform transformation computations for coordinates and grid azimuths between universal traverse mercator grid zones.

(5) When required, must perform computations for conversion of coordinates from geographic to grid and from grid to geographic.

d. The survey information center maintains accurate time by use of a chronometer and radio for dissemination to troops requiring accurate time for astronomical observations (app. I).

3–4. Division Artillery Survey Control

a. Division artillery battalions, batteries and other division installations that require survey control should be located with respect to a common grid. This grid should be the corps grid, providng starting control based on the corps grid is available. Control points based on the corps grid are normally available in the form of trig lists disseminated by the survey information center of corps artillery.

b. If known survey control is not available in the division area, the survey officer establishes a starting station and assumes data for it. This point will then establish the division grid and is the basis for all division artillery survey operations. When data on the division starting station is determined by target acquisition battalion survey elements, it then becomes necessary for division to convert their control to place it on the common (corps) grid.

c. All surveys are closed, preferably on a second known point, for both position and direction. This provides a check on the starting control, provides data for computing accuracy ratio, permits survey adjustment, and provides a check for systematic errors.

3–5. Division Artillery Survey Requirements

At each echelon of artillery, survey operations should provide the best data available at the earliest possible time. Some of the many tasks that division artillery survey parties may be required to perform are as follows:

a. Division artillery survey has the *primary* mission of providing each assigned or attached artillery unit a battalion survey control point (Bn SCP) and a line of known direction at a designated point agreed on by the reconnaissance and survey officers of both the division artillery and the unit receiving the control (battalion or battery). If timely coordination is not possible, the division artillery reconnaissance and survey officer will designate a battalion survey control point within 1,500–2,000 meters of the center of the battalion area. For the rocket battalion and in other situations when batteries are widely spread, the division artillery survey may provide two or more separate battery survey control points.

b. Division artillery survey also has the responsibility of providing survey for the battlefield surveillance radar AN/TPS–25 and other target locating devices of the target acquisition platoon, such as the visual airborne target locator (VATL), as they become available. Since the radar set requires line of sight from the antenna to the target area, the radar position area will generally be located from 1,000 to 2,000 meters behind the FEBA (forward edge of the battle area), and the radar will be emplaced and operated during darkness and periods of reduced visibility. To meet this positioning requirement, the radar position will usually be forward of the 105-mm battalions and generally in the vicinity of the observation posts. To insure coverage of the division front, a number of positions may be selected and prepared (survey, communications, etc.) for occupation by the radar section on order. After the positions have been selected and reconnoitered by radar personnel, the division artillery survey officer normally will designate one of the division artillery battalions to provide the required control to each radar position or, when necessary, will plan for the division artillery survey parties to provide the survey control. Information about the positioning of the visual airborne target locator (VATL) of the target acquisition platoon is secured from the S2. Since the survey requirements are a position and direction of fifth-order (1:1,000) accuracy, one of the battalions may be designated to provide the control or plans may be made for division artillery survey personnel to provide the control.

c. Division artillery survey parties may be required to recover and verify established survey control points.

d. Division artillery survey parties may be required to extend survey control into adjacent division areas. This requirement will normally be brought about by a desire on the part of corps artillery to strengthen the corps grid in the corps sector by increasing the number of survey tie-in points between surveys performed in adjacent division areas.

e. Division artillery survey parties may be required to extend survey control to corps field artillery battalions positioned in the division area. Quite often some of the corps artillery battalions will be positioned along the route of survey selected for division artillery survey parties. When situations such as this occur, division artillery survey will establish survey control points for the corps artillery units to conserve time and eliminate duplicate survey work. When division artillery units are positioned along the routes of survey for the corps artillery survey parties, a like procedure is followed, with the target acquisition battalion survey parties providing survey control points for the division artillery units.

f. Each of the infantry and tank battalions of the division has a 4.2-inch mortar platoon that has a position area survey requirement but no survey capability. The direct support battalions have the responsibility of providing survey control for the platoons in the battalions attached to the brigade, *after* the artillery survey requirements are fulfilled. By coordination with the direct support battalion survey officer, the division artillery survey officer may assist in meeting this requirement by establishing additional survey control points in the vicinity or by using survey personnel from units positioned in the vicinity.

g. Because of the number and variety of installations in the division requiring survey control, the division artillery survey officer, in planning the survey, must establish the proper priority for the allocation of the survey effort. Any priorities (i.e., nuclear delivery units, etc.) designated by the division artillery commander must be incorporated in the survey plan. The survey officer tries to achieve an equitable distribution of the survey effort when designating battalions to perform survey for the various installations.

Section II. CORPS ARTILLERY SURVEY OPERATIONS

3–6. General

a. Corps artillery survey operations are performed by the field artillery target acquisition battalion (FATAB) assigned to each corps artillery. The battalion commander of the field artillery target acquisition battalion is the corps artillery survey officer. The target acquisition battalion survey officer is responsible to the battalion commander for planning and supervising the battalion survey operations.

b. Provisions exist for the attachment of officers of the US Coast and Geodetic Survey to the FATAB in time of war. These officers will fill positions as directed.

3–7. Survey Mission of the Target Acquisition Battalion

The survey mission of the target acquisition battalion is to provide survey control executed to a prescribed fourth-order accuracy to each of the following:

a. Division Artillery. Depending on the tactical situation and the deployment of units in the corps area, the target acquisition battalion will normally be required to establish a survey control point for each division artillery. Directional control must be provided at each of these central points.

b. Corps Field Artillery Battalions. The target acquisition battalion is responsible for extending survey control to each field artillery battalion operating in the corps area as corps artillery. The survey requirements of these battalions are that a survey control point be established within 1,500–2,000 meters of the position area and that direction from the point to an azimuth mark be provided.

c. FATAB Target Locating Installations. The target acquisition battalion must locate the following organic target locating devices:

(1) *Microphones in the sound base.* Since each target acquisition battery normally establishes one six-microphone sound base, a total of 18 microphones must be located by survey. However, there may be times when one battery will operate a 12-microphone cross-base which will necessitate locating a total of 24 microphones.

(2) *Flash observation posts (OP) in the flash observation bases.* Since each target acquisition battery normally establishes 4 flash OP's, a total of 12 OP's must be located by survey and provided with directional control.

(3) *Radar installations.* There are six radar installations in the battalion which must be provided with survey control.

d. Meteorological Stations. The target acquisition battalion must provide survey control to each organic meteorological section of the target acquisition battalion, a total of two installations. When large-scale maps are available, only direction need be provided (fifth-order azimuth from orienting station to azimuth mark). When large-scale maps are not available, fifth-order accuracy requirement for the met section is a special requirement, since target acquisition battalion survey is performed to fourth-order accuracy.

e. Other Units and Installations as Required. The target acquisition battalion must provide survey control to additional units and installations designated by the corps artillery commander; e.g., Air Force radio and radar installations and air defense artillery missile units located within the corps area, including target director posts. Survey control points may also be required for air defense artillery units and searchlight batteries (platoons) in areas for which maps are not available. A fifth-order location and direction is required for searchlight batteries (platoons).

3–8. Survey Information Center

The survey information center (SIC) of the target acquisition battalion is the corps artillery survey information center. The purpose of the survey information center is to collect, evaluate, and disseminate survey information within the corps and adjacent corps areas, executed to an accuracy of fourth order or greater. The survey information center is normally located in the vicinity of the corps artillery fire direction center and, unless otherwise specified by the corps artillery survey officer, is the only authorized office for the dissemination of corps artillery survey information. The dissemination is accomplished by preparing and distributing trig lists and by furnishing survey information to personnel of other units as the situation dictates. Individual surveying elements of the battalion are not normally allowed to disseminate the results of their fieldwork to subordinate echelons. Specific responsibilities of the survey information center are as follows:

a. Survey Control Files. The survey information center maintains files of all survey control (fourth-order accuracy or greater) in the corps area. These files are composed of trig lists and extracts from trig lists, prepared and issued by the United States Army Topographic Command (TOPOCOM) or the Corps of Engineers; DA Form 3613 (Record—Survey Control Point) (fig 3–1 and 3–2) for survey control points established by the target acquisition battalion parties; tabulated data and DA Form 3613 on all survey control points established by the division artillery survey parties; and a record of tie-in survey con-

trol points established in adjacent corps areas by the target acquisition battalion and division artilleries operating in those areas.

b. Survey Information Maps and Overlays. The survey information center maintains survey information maps and overlays to aid in the rapid dissemination of required survey information to using units and to aid the battalion survey officer in planning the corps artillery survey. For surveys conducted to a fourth-order accuracy, these maps and overlays should show information as follows:

(1) Survey control points.

(2) Proposed surveys, to include, when possible, surveys proposed by the division artilleries.

(3) Completed surveys.

(4) Friendly situation and, in some cases, the enemy situation when it is such that it might affect the planning or performance of survey in the corps area.

(5) Target acquisition battalion installations.

(6) Present and proposed artillery positions in the corps area.

c. Survey Computations and Checks. The survey information center is responsible for performing the following computations and checks:

(1) The survey information center must check field records and computations of target acquisition battalion field parties. When a survey party operates in the field, party personnel maintain a complete record of all fieldwork performed (field notebook) and all computations performed (DA Forms). On completion of a survey, the field notebook, together with the computations and results of the survey (closure), are forwarded to the survey information center for checking, adjusting, and recording.

(2) The survey information center must adjust all surveys to distribute minor errors in distance and direction throughout all stations occupied in the survey. Prior to adjustment, all surveys must meet the minimum closure requirements of fourth order.

(3) When required, the survey information center must convert survey data to the corps grid by swinging and sliding operations.

(4) When required, the survey information center must perform transformation computations for coordinates and grid azimuths between universal traverse mercator grid zones.

(5) When required, the survey information center must perform computations for conversion of coordinates from geographic to grid and/or from grid to geographic.

d. Maintains accurate time by use of a chronometer and radio (to agree with the National Bureau of Standards) for dissemination to troops requiring accurate time for astronomical observations (app I).

3–9. Survey Organization of the Target Acquisition Battalion

To perform and supervise survey operations, the target acquisition battalion is authorized personnel as follows:

a. Target Acquisition Battalion Commander. The target acquisition battalion commander is the corps artillery survey officer. He is a lieutenant colonel and a member of the corps artillery commander's staff. Assisted by the battalion survey officer, he is responsible for the overall planning, execution, and supervision of the corps artillery survey.

b. Battalion Survey Officer. The battalion survey officer, a major, is a member of the battalion staff. Under the direction of the corps artillery survey officer (target acquisition battalion commander), the survey officer's duties are as follows:

(1) Plan the corps artillery survey.

(2) Coordinate the survey of the target acquisition battalion with all other artillery units in the corps area.

(3) Maintain liaison with, and obtain control data from, the topographic (topo) engineer unit operating with the corps.

(4) Establish the survey information center (SIC).

c. A survey technician warrant officer, assigned to headquarters battery, supervises the operation of the survey information center.

d. A survey platoon is assigned to each battery of the target acquisition battalion. The platoon commander is the survey officer of the battery. He plans and supervises the operations of the survey platoon and advises the battery commander on matters pertaining to survey.

3–10. Coordination of Responsibilities Between Echelons

In establishing the common grid in the corps area,

coordination between all echelons must be continuous. The target acquisition battalion survey officer at corps artillery works closely with the corps topographic engineers. In an active theater of operations, the engineers are responsible for providing survey control within 1,000 meters of any missile launching site to the rear of corps. This work, though normally done by the Corps Topographic Company, will often require the attention of the corps artillery survey officer or the survey officer of the target acquisition battalion. Furthermore, from the corps rear boundary forward, the artillery target acquisition battalion is responsible for providing survey control to within 1,000 meters of the missile launching sites and it may be necessary in some cases to request assistance from the engineer geodetic survey team to expedite operations. The target acquisition battalion survey officer also coordinates with the survey officers of each division artillery. Quite often, it is obvious during the coordination of survey plans between division artillery and corps artillery that some of the corps artillery battalions will be positioned along the route of survey selected for division artillery survey parties. When situations such as this occur, division artillery survey will establish battalion survey control points for the corps artillery units, thus conserving time and eliminating the duplica-survey control points for the corps artillery units, are positioned along the routes of survey for the corps artillery survey parties, a like procedure is followed, with the target acquisition battalion survey parties providing battalion survey control points for the division artillery units.

3–11. Coordination and Supervision of Target Acquisition Battalion Survey

The battalion survey officer normally is authorized by the battalion commander to issue instructions directly to the batteries on matters concerning survey operations. The battery survey officers normally receive the survey instructions for their batteries from the battalion survey officer. The relations between the battalion survey officer and the battery survey officers in issuing and receiving instructions are similar to the relations between the fire direction officer in a howitzer or gun battalion and the battery executive officers. The battery survey officers must keep their battery commanders informed of the survey operations that they have been instructed to perform. They must also keep their battery commanders informed of the areas in which the battery survey platoon will be operating and the progress of the survey operations.

3–12. Target Acquisition Battalion Survey Operations

Target acquisition battalion survey operations are conducted in two phases as follows:

a. Initial Phase. The survey operations conducted during the initial phase consist of those necessary to establish a survey control point for each division artillery and each corps artillery battalion (and other points as directed by the battalion commander) and those necessary to establish survey control for the installations that are organic to the target acquisition battalion which require survey control.

b. Expansion Phase. The survey operations conducted during the expansion phase consist of surveys necessary to place survey control points within 1,500 to 2,000 meters of any possible field artillery position in the corps area (see para 3–13).

Note. Survey operations of the target acquisition battalion are continuous. The amount of survey performed by the target acquisition battalion in any area of operations depends on the length of time that the corps remains in the area. When the corps is moving rapidly, the target acquisition battalion may be able to perform only the initial phase survey operations. When the corps remains in one area for an extended period of time, the target acquisition battalion conducts extensive survey operations.

3–13. Survey Control Points

Survey parties of the battalion establish a semi-permanent survey station approximately every

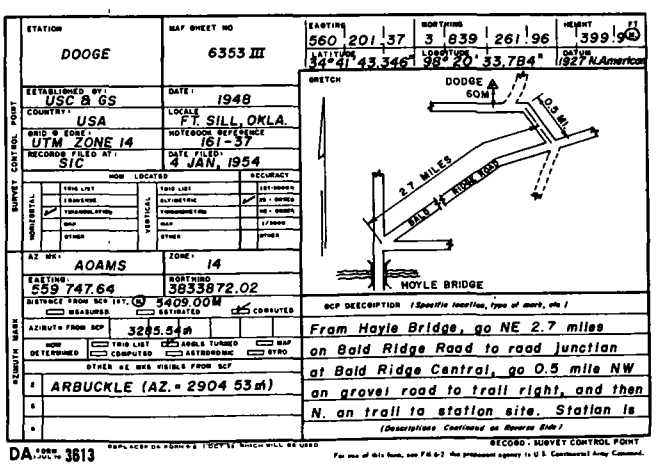


Figure 3–1. Entries made on the front of DA Form 3613.

1,500 to 2,000 meters along the routes of the surveys. A station of this type is established at each survey control point provided for division artillery and the corps artillery battalions, as well as for those points from which target acquisition battery installations are located. A semipermanent station is also established at each point designated for later extension of control and for checking surveys. Each of these survey stations is marked by a hub, shell casing or concrete monument (para 9–5*b*) and a reference stake. An azimuth for each such station is established either to an azimuth mark or to an adjacent survey station. A description of each station is prepared on DA Form 3613 and filed at the survey information center (fig 3–1 and 3–2).

3–14. Planning Target Acquisition Battery Survey Operations

The points for which survey control must be established by the survey platoon of each target acquisition battery fall into two general categories, those for installations of the target acquisition battalion and those for installations of other units. The commander of a target acquisition battery survey platoon plans the initial phase operations of the platoon by first considering the operations necessary to establish the location of the target acquisition battery installations. He then modifies this plan, as necessary, to provide survey control for the installation of other units. If priorities have been established by the battalion survey officer, the platoon commander must incorporate them into his survey plan.

3–15. Target Acquisition Battery Survey Operations During the Initial Phase

The survey operations performed by a target acquisition battery survey platoon during the initial phase consist of the survey operations necessary to establish the location of the target acquisition battery installations that require survey control and to provide a survey control point for the division artillery and for each corps artillery battalion in the platoon's area of responsibility. All or part of the target acquisition battery survey operations may be started by using assumed coordinates and height. For example, if survey control points do not exist in the vicinity of the selected sound base microphones, the sound base survey (and location of any survey control points along the line of the sound base) is frequently performed by two parties starting at a point near the center of the sound base and using assumed data, while a third party extends survey control to the starting point.

SCP DESCRIPTION (Continued)

located 60 meters N of centerline of gravel road and 30 meters S. of Dodge Hill and Control Blockhouse. Station is a standard USC & GS bronze disk stamped "Dodge, 1948" and set in concrete and is further identified by a metal quad signal erected over station. (Station Field checked 7 JULY 1968).

AZ MK DESCRIPTION

From Hoyle Bridge, go SSE 1.9 miles along gravel road to road junction and thence ESE 0.7 mile along gravel road to top of hill and station site. Station is a 1-inch iron pipe set in concrete and located 45 meters E. of road. A metal quad signal is erected over station.

DESCRIPTION PREPARED BY	DESCRIPTION CHECKED BY	DATE
A. LORENZ	W. TATE	7 JULY 68

Entries made on the back of DA Form 3613.

3–16. Illustrative Example of a Target Acquisition Battery Survey During the Initial Phase

An example of survey operations conducted by a target acquisition battery survey platoon during the initial phase is shown in figure 3–3. Each survey station shown in the figure is a semipermanent survey station. At each of these stations an azimuth was established, either to an azimuth mark (az. mk.) or to an adjacent survey station. Important points to note about the planning of this survey are as follows:

a. Equal Workload Distribution. The three parties of the battery are performing approximately the same amount of field work. Because of this equal distribution of work, all parties should finish about the same time and the survey will be ready for adjustment at the earliest possible time.

b. Survey is Closed. The survey is closed since it was planned as a loop. All intersections to locate observation posts are checked. (All intersections and resections should be checked and, though the check does not necessarily have to be completed during the initial phase, this is usually the most convenient time to do so.) Survey control will be extended into the zone of the adjacent target acquisition battery to provide a tie-in and additional check on the work performed. The unit SOP will generally designate whether the target acquisition battery surveys will close with adjacent platoons from left to right or right to left, and the target acquisition battalion survey officer will normally designate the point for the tie-in.

c. Microphone Survey Conducted by One Party. For a regular straight microphone base, the sur-

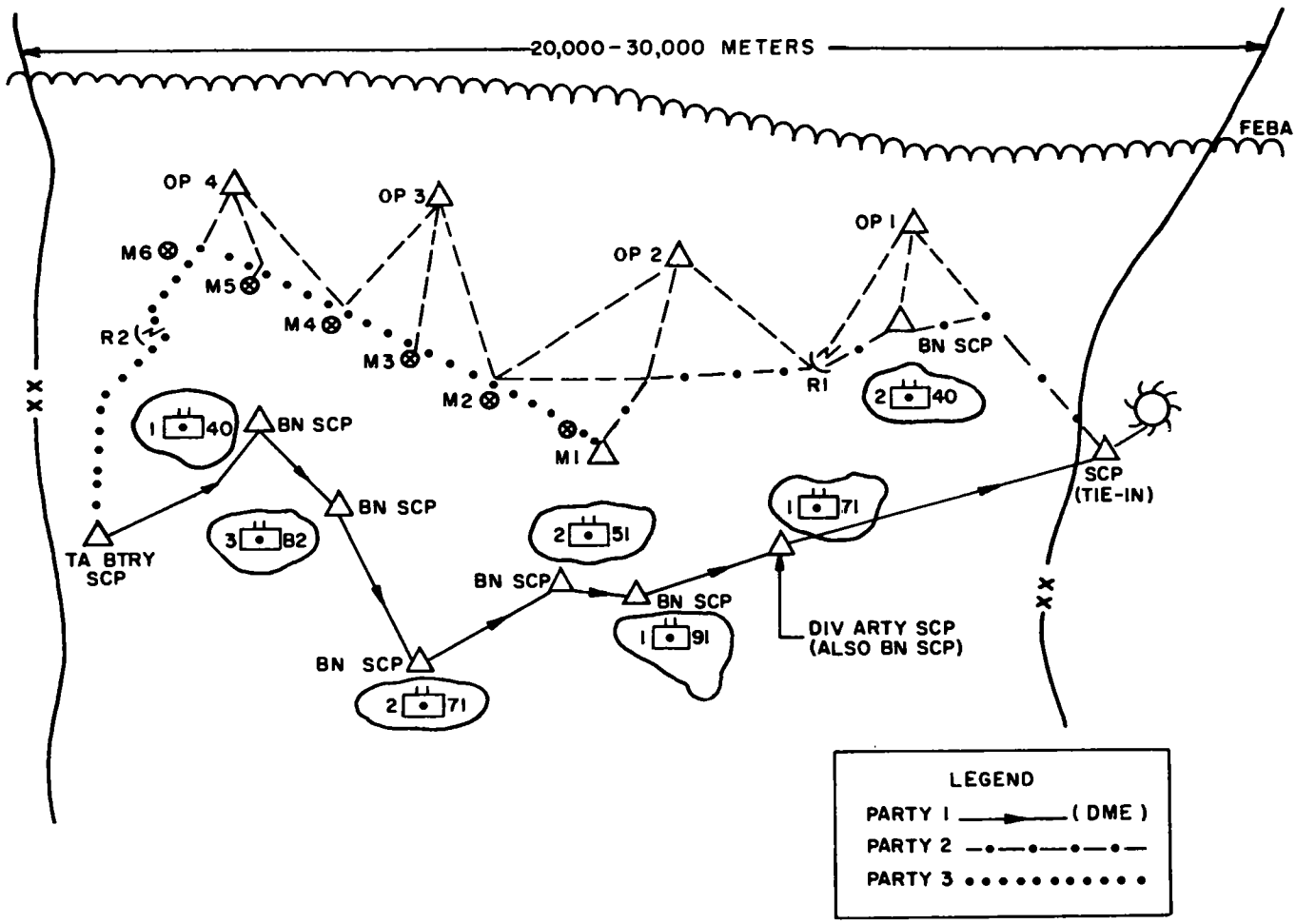


Figure 3-3. Sketch illustrating target acquisition battery initial phase survey.

vey is usually conducted by one party. Another acceptable method is to use two parties for the microphone base with both parties starting from the same point or from two separate points on the same grid in order to assure the proper relative location of the microphones to each other. If the microphone base is irregular, there are no restrictions imposed on the planning.

d. Battalion and Division Artillery Survey Control Points Provided. Survey control points are provided within 1,500–2,000 meters of the position area of all corps artillery battalions, and a survey control point is provided for division artillery at a place agreed upon by the target acquisition battery and division artillery survey officers.

e. Method of Survey. The primary method of survey used to extend control during the initial phase will normally be DME traverse because of the numerous installations requiring survey and the amount of terrain to be covered. Triangulation, however, would be acceptable if the terrain and the organization on the ground of the installations to be surveyed readily lend themselves to this method. Double intersection to the flash observation posts, or to a point near each observation post is usually the method employed for the survey of the flash base. However, other methods, such as triangulation, traverse, or resection, might be employed for this purpose. One of the primary factors which must be considered in surveying the flash observation posts is enemy surveillance, since flash observation posts are positioned at points which provide unrestricted visibility to the enemy zone.

3–17. Illustrative Example of Survey by the Headquarters Battery Survey Platoon During the Initial Phase

During the initial phase survey, the target acquisition battery survey platoons are employed in their respective battery areas. The survey platoon

of headquarters battery is normally employed to bring survey control forward from the corps rear area (fig 3–4) thus establishing a basic corps net. The method of survey used to accomplish this is normally DME traverse because of the great distances usually involved. If control already exists in the corps area and extension of control from the rear is not required, then the target acquisition battalion survey officer may either divide the headquarters battery survey platoon to assist the target acquisition battery survey platoons in performing the initial phase survey, or he may start them at once on the expansion phase survey.

3–18. Survey Operations During the Expansion Phase

a. Survey operations of the target acquisition battalion during the expansion phase are those operations necessary to expand the basic net throughout the corps area. The ultimate goal is a survey control point within 1,500 to 2,000 meters of every probable artillery position. This is accomplished to the extent permitted by the time available.

b. During the expansion phase, the survey platoons of the battalion are assigned tasks by the battalion survey officer as necessary to accomplish the required survey operations. The survey platoon of each battery should be assigned tasks in areas as near as possible to its battery area. This is necessary to facilitate future operations of the corps and to reduce the problems of movement from the battery area and of messing.

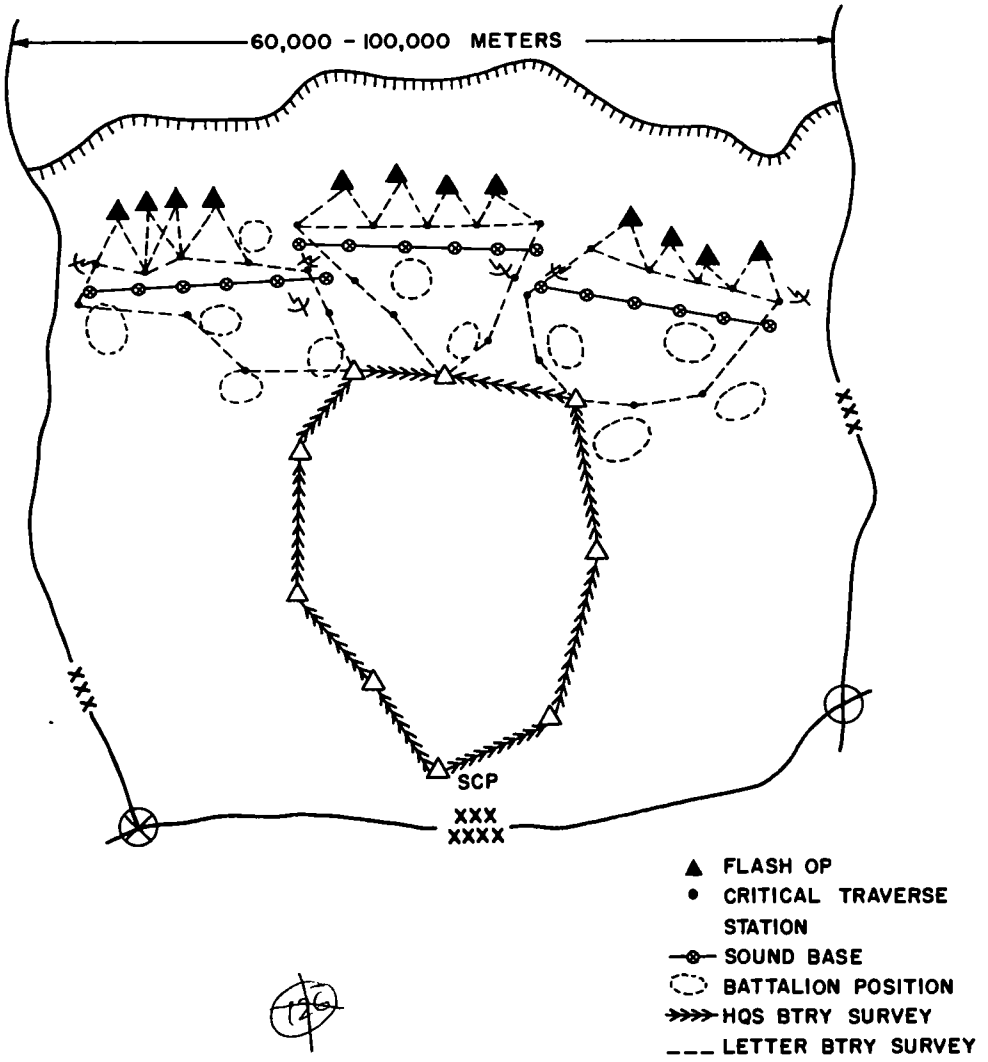


Figure 3–4. Sketch illustrating the extension of survey control forward from the corps rear by the survey platoon of headquarters battery.

c. Figure 3–5 illustrates the survey operations of a target acquisition battalion during the expansion phase.

3–19. Requirements for Sound Base Survey

To be able to locate a sound source by sound ranging, the microphones of the sound ranging base must be accurately located by survey; that is, the grid coordinates of each microphone position must be known or determined by survey.

a. Regular Bases. Because the microphones of a regular base must be equidistant and must have a specific linear relation, the coordinates required for the microphone positions *must first be computed, and then the positions must be located on the ground by survey operations.* To compute the coordinates of the microphone positions, the following data must be known:

(1) The subbase length.
(2) The number of microphones.
(3) The radius of the base, if curved.
(4) The azimuth of the base.
(5) The coordinates of a point on the base (microphone or midpoint).

b. Irregular Bases. Since the microphones of an irregular base do not have a specific subbase length or linear relation, the desired points are located on the ground by map or ground recon-

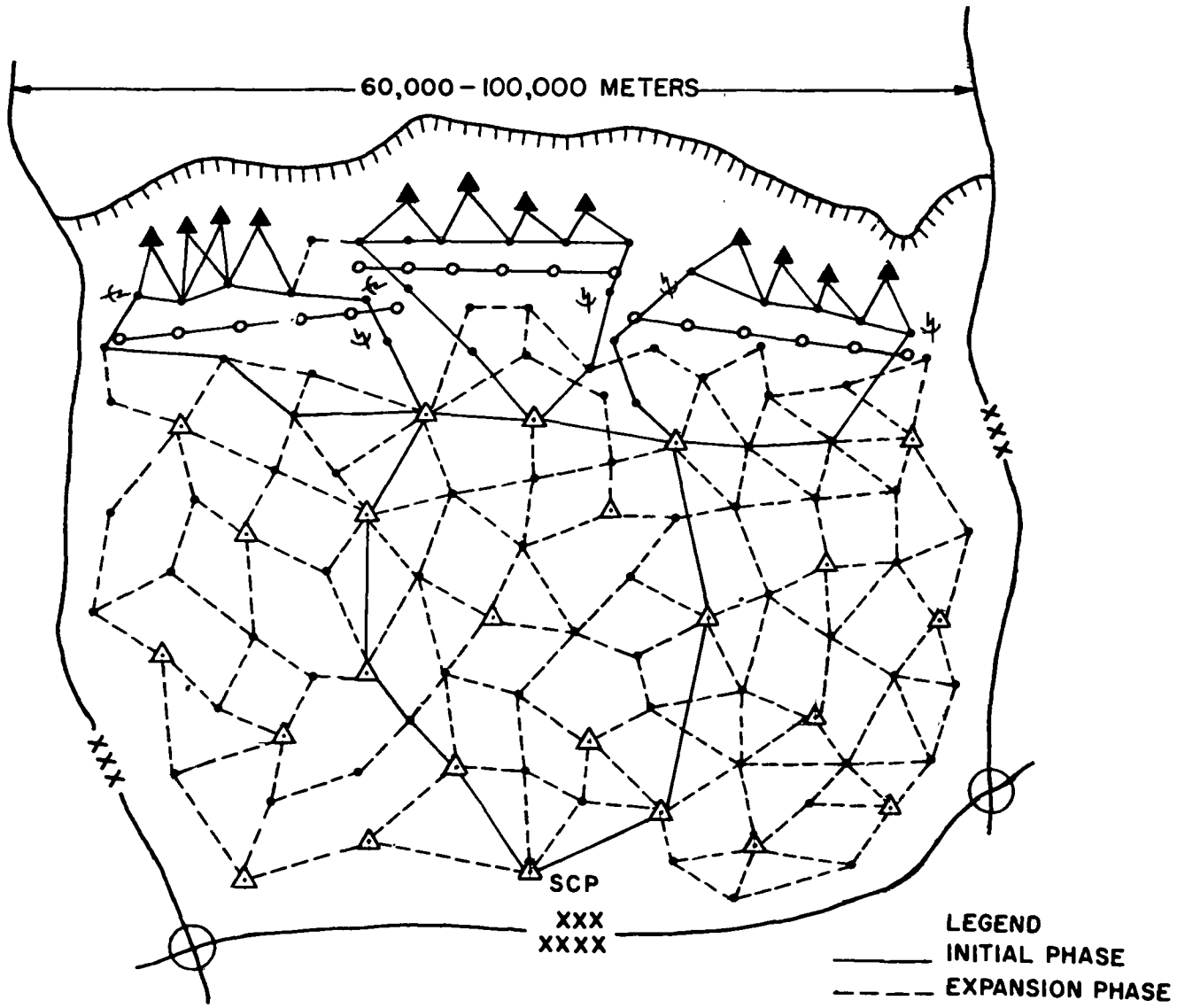


Figure 3–5. Sketch illustrating target acquisition battalion survey operation during the expansion phase.

naissance, and their coordinates are determined accurately by survey.

3–20. Computing Microphone Positions for a Regular Straight Base

When the survey officer has recieved the information from the sound platoon leader concerning the type, size, number of microphones, azimuth of the base, and coordinates of one microphone, he will have the computers determine the coordinates of all microphones. Using the azimuth of the base and the subbase length, the computers will determine the difference in easting (dE) and the difference in northing (dN) for one subbase. In a straight regular sound base, the dE and dN for all subbases will be the same. For computing the dE and dN for the subbase, the log scale factor must be used, since the speed of sound (377.6 meters per second) is based on ground distance. The coordinates of the other microphones are determined by applying this dE and dN to the coordinates of the given microphone. The computation of the microphone locations may be accomplished on DA Form 6–2 (Computation—Coordinates and Height From Azimuth, Distance and Vestical Angle). Microphones should be located as near the same height as feasible not to exceed 60M difference in height between adjacent microphones. If maps are available, heights may be extracted from the map. If maps are not available, vertical control should be carried to the microphone position.

3–21. Surveying Microphone Positions for a Regular Straight Base

As soon as practical after the location of the sound ranging base has been determined by a map and ground reconnaissance and the coordinates of the microphone positions have been computed, the microphone positions are located on the ground at their computed positions by survey operations. Traverse is the most frequently used survey method. If survey control is available at a point on or near the base, the survey may start from this point. Prior to actual survey operations, the coordinates of each microphone are plotted on a map and height of each is determined. The traverse for the microphone base survey is then planned so that one traverse station will be occupied within 200 meters of each plotted microphone position. The microphone positions will be located by offset survey from these traverse stations. The procedure for performing offset survey is as follows:

a. Since the coordinates of the microphone have been computed and the coordinates of the traverse station within 200 meters of the microphone position have been determined by survey, the azimuth and distance from the traverse station to the microphone position can be determined by computation on DA Form 6–1 (Computation—Azimuth and Distance From Coordinates). In performing the distance computation on DA Form 6–1, it is not necessary to apply the log scale factor, since the determined distance should be less than 200 meters and any correction from grid to ground distance would be negligible and would not materially affect the location of the microphone. The distance determined by these computations will be the distance that the tapemen must tape from the traverse station (TS) to the microphone position. If the distance exceeds 90M, it should be double-taped or checked by pacing. The azimuth along which the tapemen must tape is the azimuth determined.

b. When the azimuth and distance have been determined (*a* above) by computation, the azimuth from the traverse station to the microphone must be materialized on the ground. This is done in the following manner (fig 3–6): Subtract the azimuth to the rear traverse station from the azimuth to the microphone as computed on DA Form 6–1 to obtain the horizontal clockwise angle from the rear station to the microphone. Set up an instrument (theodolite) over the traverse station. Point the instrument (theodolite) on the rear station and read the horizontal circle. Add the reading on the instrument to the computed angle. When this value is placed on the theodolite by use of the horizontal tangent screw, the telescope will be pointing in the direction of the microphone. A range pole will then be set at some distance out from the traverse station (TS1) beyond the microphone position and along the directional line materialized by the instrument. The tapemen will then tape along the line established by the instrument and the range pole, placing a stake in the ground to mark the microphone position at the computed distance (*a* above) from the traverse station (TS1). If height is to be determined, a vertical angle is measured to the top of the stake.

3–22. Survey Control for Flash Ranging Observation Posts

Flash ranging observation posts are located in the same manner as observation posts for field artillery battalions (para 2–14), except that the survey performed must comply with fifth-order specifications (app B).

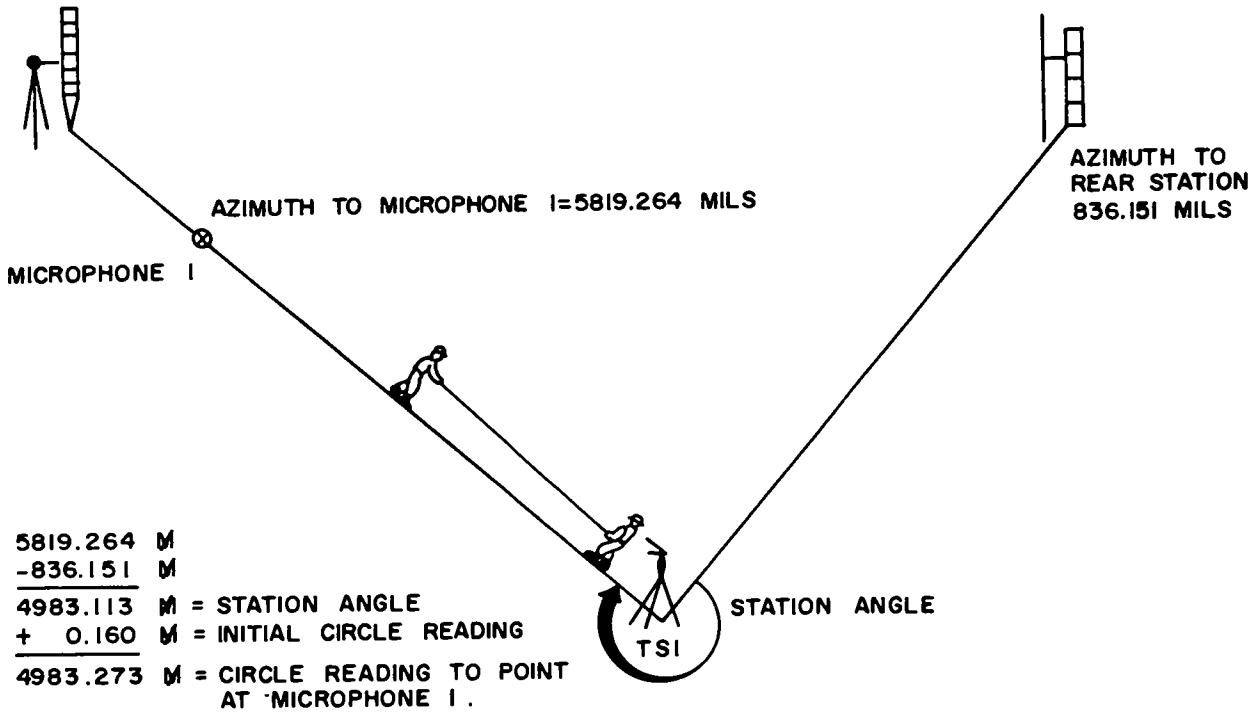


Figure 3-6. Sketch illustrating the offset technique of locating a microphone position.

CHAPTER 4

Section I. FIELD ARTILLERY GROUP SURVEYS

Section I. FIELD ARTILLERY GROUP SURVEYS

4-1. Field Artillery Group

a. The field artillery group headquarters battery has not capability for performing survey operations. The battalions of the group normally are furnished survey control by the artillery headquarters with which the group is working. When survey has not been furnished by such headquarters, the group commander may designate one battalion to establish a group survey control point. When heavy battalions of a group are required to perform target area surveys, the group commander usually designates one battalion to perform the target area surveys for the entire group.

b. The group assistant intelligence officer (assistant S2) is also the group survey officer. During training, the group survey officer supervises the training of the survey personnel of the battalions of the group. The group survey officer coordinates the survey operations of the battalions of the group. He verifies that survey control points are provided by the next higher survey echelon. He verifies, by frequent inspections, that the survey sections of the group battalions perform survey operations properly. Two enlisted survey specialists are assigned to group headquarters battery for the purpose of assisting the group survey officers in carrying out his responsibilities.

4-2. Field Artillery Battalion Group

In addition to normal survey responsibilities, the commander of a battalion group has survey responsibilities similar to those of a group commander. If survey control has not been furnished to the battalion group by the artillery headquarters with which it is working, the commander of the battalion group directs the survey officer of his battalion to establish a battalion group survey control point.

Section II. AIR DEFENSE ARTILLERY SURVEYS

4-3. General

a. Four major factors determine the type and the extent of survey operations which must be performed by or in support of air defense artillery (ADA units). These factors are the—

(1) Type of mission assigned to the unit.
(2) Availability of maps.
(3) Restrictions placed on air defense fire.
(4) Fire distribution system being used.

b. When air defense artillery units are assigned air defense missions, they must be capable of transmitting, from one unit to another, information concerning the location of aircraft. To transmit this information, the units must be located with respect to a common grid. When suitable maps are available, units can be located with respect to a common grid by map inspection for both position and direction. When suitable maps are not available, units must be located with respect to a common grid by extending control to each unit from control points located on the grid.

c. When air defense artillery units are assigned air defense missions and are restricted from firing in certain areas, they must be located with respect to the grid on which the limits of the restricted areas are designated. Units must be located on the grid by extending control to each fire unit from control points located on the grid.

d. When air defense artillery units are assigned field artillery type missions, their survey requirements are the same as those for field artillery units.

e. Air defense artillery battalions normally do not have the capability of performing survey.

Control must be extended by an agency having suitable survey equipment and trained survey personnel. Arrangements should be made for the nearest engineer or field artillery unit capable of providing the control to perform the necessary survey operations. When employed in a corps area, coordination for extending survey control to air defense artillery units should be made through the corps artillery survey officer.

4–4. Surveys for Air Defense Artillery Automatic Weapons Battalions Not Equipped With Electronic Fire Control

a. Unless there are restricted areas, survey control is not required for air defense artillery automatic weapons (ADA AW) battalions not equipped with electronic fire control systems. However, the relative locations of weapons and early warning observation posts must be known so that an early warning system can be established. When suitable maps are available, the relative locations of the weapons and observation posts are determined by map inspection. When suitable maps are not available, the relative locations can be established by limited rough survey as explained in FM 21–26.

b. When there are restricted areas, survey control is established to determine the relative horizontal and vertical locations of each weapon and to provide an orienting line for each weapon. Control is extended to each weapon from survey control points established within 1,000 meters of the position. Extension of control to the weapons must be performed to a prescribed accuracy of 1:500.

c. When ADA AW battalions are required to accomplish the surveys discussed in *b* above, the necessary survey support must be made available from the sources outside the battalion.

4–5. Acquisition Radars

a. The location of each air defense artillery acquisition radar position must be established on the Universal Transverse Mercator (UTM) or Universal Polar Stereographic (UPS) grid for the zone. When suitable maps are available, the position can be located by scaling from a map, and direction can be determined with a declinated aiming circle.

b. When suitable maps are not available, the horizontal and vertical locations of each acquisition radar are determined and a line of known direction established by extending control from a control point on the UTM (or UPS) grid for the zone by survey operations executed to fifth-order accuracy,

4–6. Air Defense Artillery Battalions

a. Nike-Hercules. The location of each target tracking radar of air defense artillery battalions, Nike-Hercules, must be established on the UTM (or UPS) grid for the zone. The height above mean sea level and a line of known direction for each target tracking radar must also be established to an accuracy of artillery fifth-order survey, and the line of direction to plus or minus one minute of arc (0.3 mil). Survey operations may be performed by engineer or field artillery units possessing the necessary capability. Temporary survey control may be established by scaling from a map, when suitable maps are available, and by using a declinated aiming circle. However, the accuracy thus obtained is adequate only for the surface-to-air mission and is acceptable only as a matter of expediency. Extension of survey from the target tracking radars to other battery radars and to the launching sections is performed by battery personnel using organic equipment. The accuracy required for this survey extension to other battery radars is prescribed in equipment technical manuals; the accuracy required to launching sections is 1:500.

b. Hawk. Directional control for Hawk battalions may be established by scaling from a map, when suitable maps are available, and by using a declinated aiming circle.

4–7. Air Defense Artillery Fire Distribution Systems

The location of each fire distribution system must be established on the UTM (or UPS) grid for the zone. Survey operations may be performed by engineer or field artillery units possessing the necessary capability. An accuracy of artillery fifth-order survey is required.

CHAPTER 5
SURVEY PLANNING

5–1. Survey Missions

a. The general mission of artillery survey personnel is to provide accurate and timely survey data to artillery units and installations. Successful accomplishment of this mission requires careful preparation and the formulation of a survey plan which is as complete as possible.

b. The specific mission of artillery survey personnel for any survey operation is contained in orders and instructions issued by the organization commander. These orders and instructions are contained in the unit SOP (standing operating procedures), operations orders, and training directives.

c. After the commander has issued orders and/or instructions which require the execution of survey operations, the survey officer must plan the operations and issue the necessary instructions to survey personnel to execute the assigned mission in the prescribed time period.

5–2. Factors Affecting Survey Planning

The artillery survey officer must consider many factors in formulating the plans by which the survey mission is to be accomplished. The factors which affect survey planning cannot be considered independently because each is related to the other.

a. Tactical Situation. The enemy and friendly situations have a strong influence on survey operations, since the disposition of troops may dictate whether certain terrain may be occupied, certain routes may be used, or survey signals may be erected at stations.

b. Mission. The mission of the unit as well as the survey mission will affect survey planning. The survey officer, in his planning, must be aware of the general situation as well as the details.

c. Number of Installations. The number and location of field artillery installations must be considered primarily with respect to time and personnel available. The survey operation necessary to locate a small number of widely scattered installations will often require more time and/or personnel than would be required for a large number of closely grouped installations. In the survey plan, the survey tasks should be so allocated that the various parties executing the survey will complete their tasks in the most expeditious manner.

d. Survey Control Available. More extensive survey operations are required in areas where limited survey control exists. In areas where survey control is dense, careful planning can do much to expedite the operation.

e. Training of Personnel. The survey plan must include methods which are completely familiar to all personnel.

f. Time. The time allotted for survey will influence not only the choice of methods to be used but also the amount and type of control which can be extended.

g. Terrain. The type of terrain over which survey control must be extended is a primary factor in determining the method of survey to be used. The survey officer should be so familiar with the effects of various types of terrain on survey operations that he can promptly and properly advise his commander on the time and personnel requirements for survey operations.

h. Weather. Adverse weather will greatly reduce or eliminate the capability of survey parties. Fog, rain, snow or dust can reduce visibility to the extent that observations through an optical instrument are impossible. Heavy rain or snow can make field work virtually impossible. Extreme heat or cold can reduce the efficiency of a party to the extent that the time necessary to finish a phase must be considerably increased.

i. Availability of Special Equipment. The availability and operational readiness of such special equipment as electronic distance measuring units and gyroscopic orientors must be considered. The availability of this equipment can greatly affect

the time and effort required for a survey operation. In addition, the use of special techniques such as simultaneous observations can materially affect the accomplishment of the survey mission.

j. Priority. Any priority for survey control established by the commander or indicated by the tactical situation, must be considered in developing the survey plan.

5-3. Methods of Survey

In addition to being able to properly evaluate the factors which will affect the survey, the survey officer must have a knowledge of the methods of survey which might be used and of the advantages and disadvantages of each.

a. Traverse. For most battalion survey operations, traverse is the most suitable to use. It is a rapid and flexible means of extending control. Traverse does not require as much reconnaissance as triangulation and is extremely easy to control in the field. It is ideally suited for survey in gently rolling or flat terrain or for extending control along roads and trails. For planning purposes, a well trained traverse party can extend control over open and gently rolling or flat terrain at a rate of approximately 1,000 meters per hour.

b. Triangulation. Triangulation is a means of extending control over long distances in relatively short periods of time. It is ideally suited for survey in difficult terrain and for crossing over obstacles which cannot be taped. The primary disadvantage of triangulation is the amount of time required for reconnaissance. For planning purposes, triangulation requires approximately 30 mintues per station plus time for reconnaissance and travel between stations. Flexibility in triangulation schemes is more limited than in traverse schemes, therefore, reconnaissance for triangulation will generally require as much time as the fieldwork, expecially in extensive triangulation schemes.

c. Intersection. The advantages and disadvantages of intersection parallel those of triangulation. Intersection must be used to locate points beyond friendly frontlines. When practicable, those locations should be checked by intersection from more than one base.

d. Resection. Resection is another method of survey which can be used to locate a point when the available time or terrain or both preclude the use of traverse or triangulation. Location by resection must be checked by a separate determination (preferably triangulation or traverse) at the first opportunity.

e. Trilateration. During periods of inclement weather when intervisibility is limited or nonexistent, or when extending control over long distances, trilateration should certainly be utilized as a method of extending control. Like triangulation, trilateration also requires considerable time for reconnaissance. Azimuths carried through trilateration schemes should be confirmed by astro or gyro means at the first opportunity.

5-4. Essentials of a Good Survey Plan

In formulating the survey plan, the survey officer must remember and strive to meet certain essentials. The survey plan must—

a. Be Simple. The plan must be understood by all party personnel.

b. Be Timely. The plan must be capable of execution in the time allotted.

c. Be Flexible. The plan must be capable of being changed if the situation warrants a change.

d. Be Adaptable. The plan must be adaptable to the terrain, situation, personnel available, weather, etc.

e. Provide for Checks. Whenever possible, the plan must provide for checks; i.e., closed surveys, alternate bases, and checks made by each member of the party.

f. Provide Required Control. The plan must provide survey control within the required accuracy to all installations which require survey.

5-5. Steps in Survey Planning

The steps in survey planning are to gather all available information organic to the mission, to make a map and a ground reconnaissance, and from these findings, to formulate a survey plan.

a. Gathering Information. From the unit commander's briefing, the survey officer gathers vital information which will influence the planning of his survey. This information should be pertinent to the—

(1) *Situation.* To include the mission of the units, status of registration, time available, zone of fires, friendly positions, firing charts to be used, etc.

(2) *Designation and location of points to be surveyed.* To include position areas, observation posts, registration points, and radar sites, as required.

(3) *Restrictions.* Restrictions on mode of travel, routes and communications.

b. Map Reconnaissance. After attending the commander's briefing and issuing a warning order to alert his personnel, the survey officer performs a thorough map reconnaissance, using any suitable map or map substitute. In making the map reconnaissance, the survey officer follows a specific procedure.

(1) *Map-spots installations.* Plots on the map those installations requiring survey control.

(2) *Selects tentative plan.* Considers all the factors which affect survey, makes a choice of methods, and arrives at a tentative plan.

(3) *Considers time.* Determines if the survey mission can be accomplished in the allotted time. If not, makes appropriate recommendations to the commander. He may recommend that additional personnel be made available, that the time allotted for survey be increased, and/or that the location of certain installations be delayed.

(4) *Determines critical areas.* Determines the most critical areas requiring detailed reconnaissance.

c. Ground Reconnaissance. After completion of the map reconnaissance, the survey officer must make a ground reconnaissance as detailed as time permits. The tentative plan selected during his map study is modified as required by the terrain. Particular emphasis is placed on reconnoitering areas which may be critical; and indications are made, where necessary, to survey officers and chiefs of party, at points where tentative plans may require revisions or close coordination.

5–6. The Survey Order

Upon completion of the ground reconnaissance, the survey officer finalizes his plans and issues his orders. The survey order contains those detailed instructions to each party not covered by SOP and general information necessary for the efficient accomplishment of the survey mission. The survey order is issued orally and generally follows the same sequence as the operation order. Often, because of the tactical situation and wide spread dispersal between units, portions of this order may be issued by radio or wire, or both. Format for the survey order is as follows:

(1) *Situation* (as it effects survey operations).

(*a*) Enemy forces.

(*b*) Friendly forces.

(*c*) Attachments and detachments.

(2) *Mission.*

(3) *Execution.*

(*a*) Concept of survey operation.

(*b*) Detailed instructions to each party.

(*c*) Instructions for more than one party.

(4) *Service support.*

(5) *Command and signal* (location of survey officers).

Note. The survey officer's responsibilities do not end with the issuance of the survey order. The success or failure of the fieldwork may depend on his close and continuous supervision. If it becomes necessary to change the plan of survey, the survey officer issues appropriate instructions to the party chief(s) concerned.

5–7. Execution of the Survey Order

Each chief of survey party plans the detailed operations of his party. His planning is similar to that of the survey officer. The mission of his party is contained in the instruction issued by the survey officer. The survey plan prepared and issued by the chief of party contains those items from the survey officer's order which his personnel must know to accomplish the survey mission and any additonal instructions which may be necessary. The chief of party supervises the operation of his party and issues additional instructions as necessary throughout the conduct of the survey. Whenever it becomes impractical to comply with the instructions received from the survey officer, the chief of party reports this fact to the survey officer or chief surveyor if either is immediately available. If neither is immediately available, the chief of party changes his survey plans as necessary to accomplish that portion of the unit's survey mission for which he is responsible. At the first opportunity, he reports his actions to the survey officer.

5–8. Standing Operating Procedures

a. A standing operating procedure (SOP) is a set of instructions setting forth the procedures to be followed for those phases of operation which the commander desires to make routine. The SOP sets down the regular procedures that are to be followed in the absence of specific instructions.

b. The SOP of a battalion (separate battery) or higher headquarters should contain a section on survey. The SOP for each echelon must conform to the SOP of the next higher echelon. Therefore, the survey portion of the SOP at each field artillery echelon should contain only those survey proce-

dures which the commander desires to make standard throughout this command. Survey items which the commander desires to make standard only for the survey unit or section of his headquarters should be contained in the SOP for that particular unit or section.

5–9. Purpose of Survey Section SOP

The purposes of the survey section SOP are to:

a. Simplify the Transmission of the Survey Order. Instructions included in an SOP need not be restated in the survey orders. For example, if the Battalion SOP limits the size of distance angles for triangulation, this information need not be included in the survey order. However, inclusion of this information in the SOP would not preclude the survey officer from restating it in the survey order for emphasis.

b. Simplify and Perfect the Training of Survey Personnel. Establishment of standard procedures for survey operations in a unit insures uniform training and minimizes the need for special instructions.

c. Promote Understanding and Teamwork. In those units which have more than one survey party, the establishment of standard procedures insures uniform performance of survey operations and minimizes the time and effort required for coordination.

d. Facilitate and Expedite Survey Operations to Minimize Confusion and Errors. When personnel become familiar with, and employ, standard signals, techniques, and procedures, they will accomplish their tasks in a minimum amount of time. Furthermore, the use of standard procedures reduces confusion and eliminates many errors, which in time, expedites survey operation.

CHAPTER 6

POSITION DETERMINATION—DISTANCE DETERMINATION

Section I. HORIZONTAL TAPING

6–1. Tapes and Accessories

a. Field Artillery survey personnel are equipped with 30-meter steel tapes for making linear measurements. Most of these tapes are graduated on one side only, in meters, decimeters (0.1 meter), and centimeters (0.01 meter), with the first decimeter graduated in millimeters (0.001 meter). There is a blank space at each end of the tape. Each tape should be assigned a number and this number is to be used for all records regarding this specific tape ((i.e., repairs) para 6–3*b*).

b. In addition to a tape, each taping team should be equipped with 2 plumb bobs, a pin and plumb bob holder, 1 clamping handle, 1 set of taping pins, 1 hand level, 1 tension handle, 2 leather thongs, 2 notebooks and 2 pencils (fig 6–1) which are described as follows:

(1) *Taping pins.* Steel pins with a ring at one end and pointed on the other are called taping pins. These pins are used for marking measured tape lengths on the ground and for checking the number of tape lengths measured since the last station. The ring and part of the pin are painted red, while the remainder of the pin is white. Taping pins are issued in sets of 11, 10 of which are given to the front tapeman and one to the rear tapeman at the start of a measurement. When a tape length is measured, the front tapeman inserts the pin into the ground at an angle of 45° and perpendicular to line of measurement, to mark the position of the tape end. After the following tape length is measured, the rear tapeman picks up the pin or arrow and carries it with him as the taping progresses. The number of pins which the rear tapeman holds at any time denotes the number of full tape lengths measured since the last station. Properly used, taping arrows will prevent "dropped" tape lengths, which are a common mistake in distance taping.

(2) *Tension handle.* The tension handle uses a linear scale and is graduated in pounds from 0 to 30. It is clipped to the tape loop and tension is applied until the specified reading (25 lbs for artillery survey) for the tape appears on the scale. The primary purpose of the tension scale in artillery survey is to train taping personnel to recognize when 25 pounds of tension is being exerted on a tape.

(3) *Clamping handle.* When measuring less than a full tape length, tension is applied by using a steel tape clamping handle. This is a mechanical device which grips the flat steel tape without kinking it.

(4) *Other equipment.* Taping will frequently require the use of other equipment. To get straight line clearance between taping points, cutting tools, such as axes, hatchets, or machetes, may be required to clear away vegetation. For alining the tape from station to station, range poles (para 9–5) are used. The Abney hand level is used during steep slope taping to aid in keeping the tape on a horizontal plane. It is also used in training to teach tapemen to keep the tape horizontal. A plumb bob is needed to transfer tape readings to ground position or to read the tape directly above a marked position on the ground. The notebooks are used to record all distances after confirmation of the measurement by the tapers. This notebook is kept in addition to the regular notebook maintained by the recorder. Each distance is recorded in *both* notebooks.

6–2. Care of Steel Tapes

a. Steel tapes are accurate surveying instruments and must be handled with care. Although steel tapes are of durable construction, they can be easily damaged through improper care and use.

b. When a steel tape is being used, it should be completely removed from its reel and kept straight to prevent its being kinked or broken. The tape should never be pulled around an object that will cause a sharp turn in the tape. Care

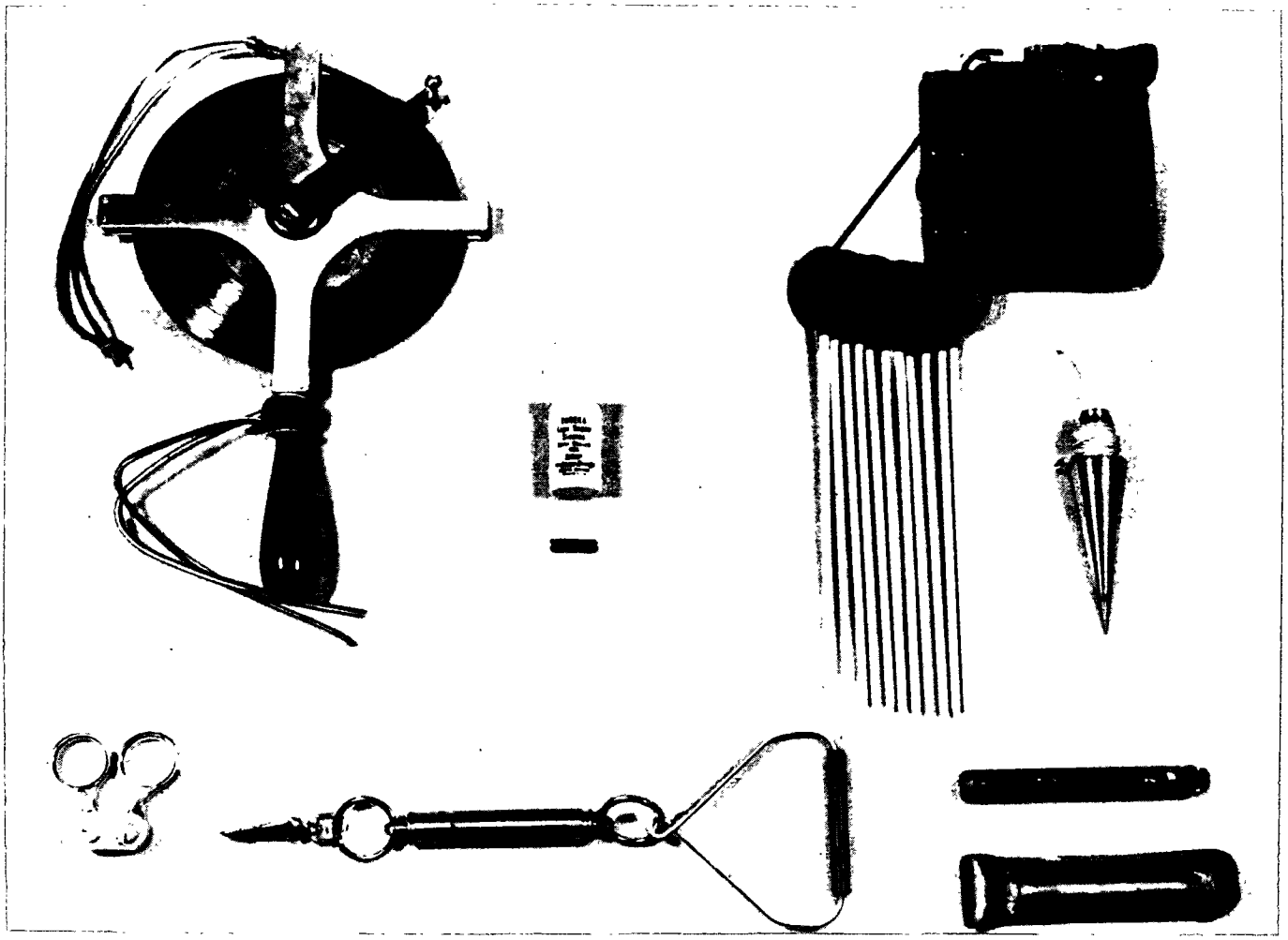


Figure 6–1. Taping equipment.

should be taken to avoid jerking or stepping on the tape or allowing vehicles to run over it. A loop in the tape may cause the tape to kink or break when tension is applied. Before applying tension, the tapeman should insure that there are no loops in the tape.

c. The tape should be wiped clean and dry and oiled lightly after each use. The tape is oiled by running it through an oily rag as it is being reeled in. The tape should be loosely wound on its reel when not in use. In winding the tape on the reel, the tapeman should insert the end of the tape with the 30-meter graduations into the reel and wind the tape so that the numbers are facing the axle of the reel.

6–3. Repair of Broken Tape

a. Regardless of how well tapes are protected and cared for, at one time or another a tape must be repaired in the field to avoid unnecessary delay in the work. For this reason, every survey party should be equipped with a tape repair kit. A tape repair kit contains a pair of small snips, the tape sections of proper size and graduations, a hand punch or bench punch with block, an assortment of small rivets, a small container of sheet metal sleeves, a pair of tweezers, and a small hammer. When repairing a broken tape, first square the broken ends. Next, arrange the broken tape with both parts alined over the spare tape section so that graduations are the correct distance apart. Select the spare tape part long enough to span distance between the squared ends and to overlap each end not less than 1 inch or 2 centimeters. If rivets are used, each overlap is then riveted so that the edges of all parts of the points are snug. This is done by placing the rivets close to the ends, about 1/16 to 3/32 of an inch or 1-1/2 to 2 millimeters. A broken tape can also be repaired by fitting

a sheet metal sleeve, coated on the inside with solder and flux, over the broken ends of the tape. The sleeve is hammered down tightly, and heat is applied to the sleeve to cause the solder to securely bind the broken ends of the tape within the sleeve. An ordinary match may be used to heat the solder.

b. The repaired tape must be compared with other tapes to insure that the ends of the tape were jointed and that the tape still gives a true measurement. Any discrepancy between the two will be recorded in the taping notebook and referenced to the tape number mentioned in paragraph 6–1*a*.

6–4. Horizontal Taping, General

a. The method of taping used in field artillery surveys is known as *horizontal taping*. In this method, all measurements are made with the tape held horizontally. The point *from which* the distance is to be measured is the *rear station*. The point *to which* the distance is to be measured is the *forward station*. The distance between stations is usually several times greater than a full tape length. The taping team, starting at the rear station, determines the distance by measuring successive full tape lengths until the distance remaining is less than a full tape length. This partial tape length is then measured. The distance between stations is determined by multiplying the number of tape lengths by the length of the tape and adding the partial tape length.

b. A taping team consists of two men—a front tapeman and a rear tapeman. The rear tapeman commands the taping team and records all distances in the taping notebook. He is responsible for the determination and reporting of the measured distance. The front tapeman independently checks the distance measurement and compares his findings with that of the rear tapeman's. Additional personnel are required for taping at night (para 6–17).

6–5. Measuring First Full Tape Length

The first full tape length is measured using the following procedures:

a. The front tapeman gives 1 taping pin to the rear tapeman, keeping 10 pins in his possession. The pin given to the rear tapeman represents the first full tape length. The front tapeman moves toward the forward station with the zero end of the tape.

b. As the end of the tape reaches the rear station, the front tapeman stops, either on his count of paces or on the command TAPE given by the rear tapeman. The rear tapeman alines the forward tapeman by sighting first toward the forward station and then in an estimated horizontal plane. The tape must be alined within 0.5 meters of the line of sight from one station to the succeeding station and within 0.5 meter of the horizontal plane.

c. Each tapeman places a leather thong on his wrist and the plumb bob cord on the proper graduation on the end of the tape. The rear tapeman alines his plumb bob roughly over the rear station and commands PULL, and the tapemen exert a pull of 25 pounds on the tape.

d. After the tapemen have properly alined and applied tension to the tape, the rear tapeman places his plumb bob exactly over the rear station and commands STICK. At this command, the front tapeman drops his plumb bob and then marks the point of impact by inserting a taping pin into the ground perpendicular to the line of measurement at an angle of approximately 45° to the ground. After the pin is firmly emplaced, the front tapeman announces STUCK. This is the command for the rear tapeman to move forward to the next pin position while the front tapeman advances 30 paces to measure the next tape length.

e. When a team is taping on gently sloping ground void of brush and tall grass, the plumb bob need not be used at the uphill end of the tape. The end of the tape may be held immediately adjacent to the taping pin.

6–6. Moving Forward

a. The front tapeman should select as a guide a landmark (rock, bush, etc.) in line with the forward station. In moving forward, the front tape-

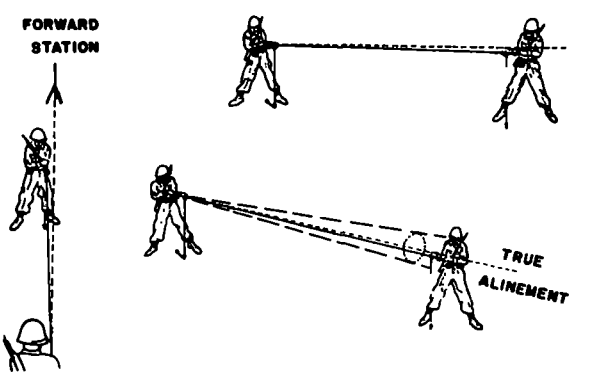


Figure 6–2. Tape alinement.

man should keep his eyes on the line of the forward station and should not look back. He should determine the number of paces to the tape length so that he can stop without being signaled when he has moved forward a tape length.

b. By moving forward at a point 2 or 3 meters in front of the rear end of the tape, the rear tapeman can usually locate the taping pin by the time the front tapeman has stopped. In areas where the taping pin is not readily visible, the forward tapeman may be required to wait until the rear tapeman arrives at his position. Then he moves forward to make the next measurement.

c. When an instrument is used at either the forward or the rear station, the tapeman must remain clear of the line of sight as much as possible.

6–7. Measuring Succeeding Full Tape Lengths

Succeeding full tape lengths are measured as discussed in paragraph 6–5, except as follows:

a. The front tapeman should obtain his approximate horizontal alinement by sighting back along the tape toward the rear station, moving right or left until the tape is approximately on line. Final alinement usually is made as directed by the rear tapeman. However, if the rear tapeman cannot see the forward station, final alinement is made either by the front tapeman sighting back on the rear station or by the rear tapeman through the use of previously selected reference points in alinement with the forward station. The instrument operator, if available, may assist in the alinement.

b. The rear tapeman should place his plumb bob exactly over the point at which the taping pin enters the ground.

c. The rear tapeman pulls the taping pin from the ground after the front tapeman commands STUCK and then moves forward to the next pin position. If a taping pin is lost during the measurement of the distance, the tapemen must tape the entire distance again, rather than complete the taping from a recovered pin hole.

6–8. Tape Alinement

The tapemen must carefully aline the tape. The maximum allowable error in both horizontal and vertical alinement is one-half meter for a full 30-meter tape length. The tapemen aline the tape with the stations which establish the line by sighting along the tape toward the stations at each end of the line (fig 6–2). The tapemen then level the tape horizontally by holding it parallel to an estimated horizontal plane. If difficulty is encountered in keeping the tape level in rough terrain, then the hand level should be used. To use the hand level to establish a horizontal plane, the downslope tapeman—

a. Sights through the level at the upslope tapeman.

b. Raises or lowers the objective end of the hand level until the image of the level bubble is centered on the horizontal crossline.

c. Determines the point on the upslope tapeman which is level with the eye. This establishes the horizontal plane.

d. Instructs the upslope tapeman how to hold his end of the tape so that the tape will be parallel to the established horizontal plane. The downslope tapeman must hold the tape no higher than his armpits. Both tape ends should be held the same distance below the established horizontal plane.

Note. The tapeman should check the accuracy of the bubble of the hand level when it is first used each day. This is accomplished by having the upslope tapeman use the hand level to sight on the downslope tapeman to establish the horizontal plane. The procedure is then reversed to verify the established horizontal plane.

6–9. Applying Tension to Tape

The tapeman must apply 25 pounds tension (pull) to each full or partial tape length.

a. The tapeman should apply tension to the tape by using the leg muscles and the large muscles of the back. To do this, the tapeman faces across the tape with his shoulders parallel to the length of the tape, passes the hand of the arm which is away from the other tapeman through a loop in the thong, and places the elbow of that arm tight against some part of his body (fig 6–3). When the tapeman is standing he applies tension by bending the knee which is away from the other tapeman, causing the weight of the body to push against the arm holding the tape. When the tapeman is kneeling, he applies tension by pushing the knee which is away from the other tapeman against the arm holding the tape.

b. The clamping handle is used to hold the tape at any point other than a tape end. In order to avoid kinking the tape, the tapeman should hold the clamping handle with the index and middle fingers. Normally, the handle will clamp as tension is applied to the tape. If additional pressure is

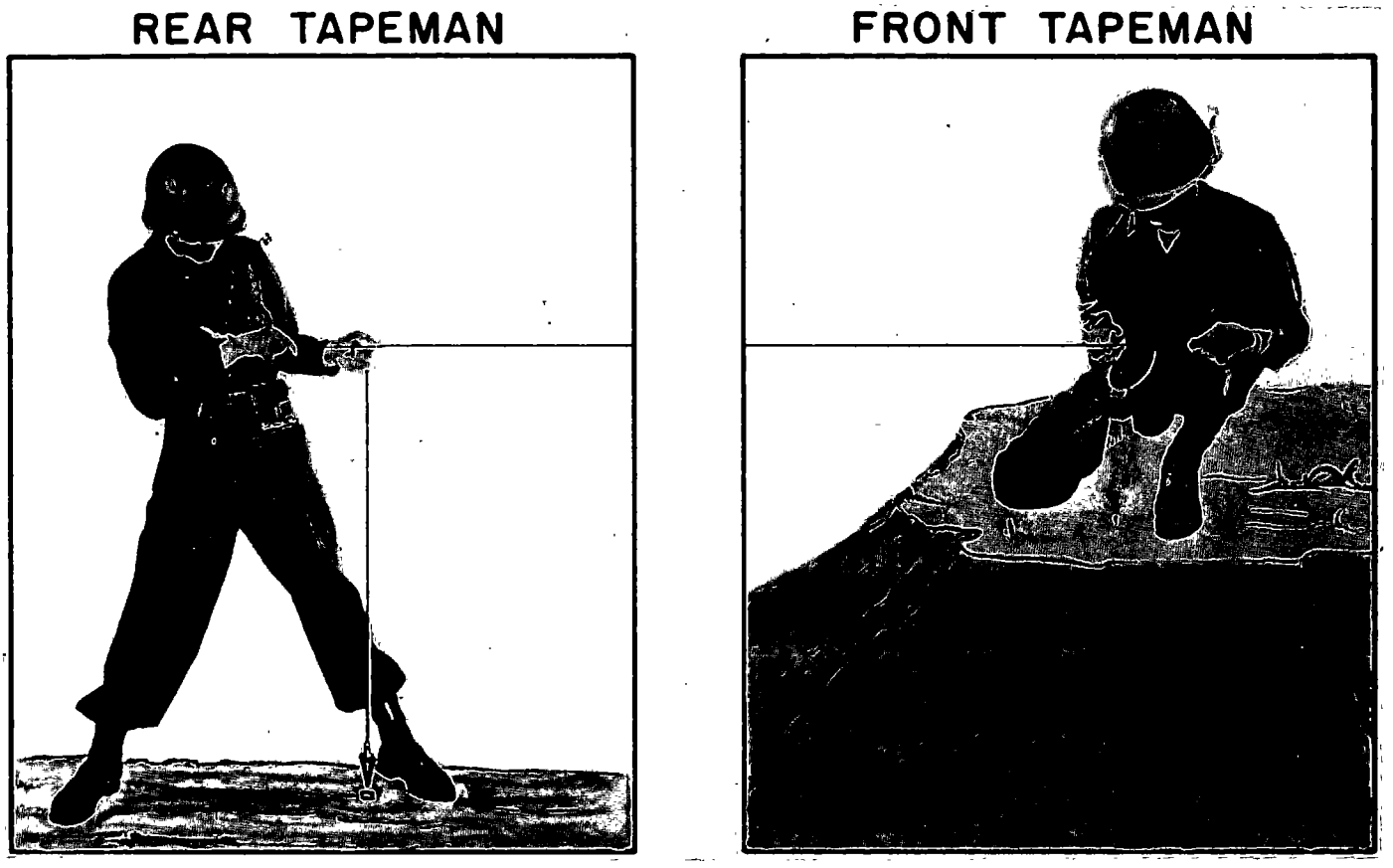


Figure 6–3. Applying tension to a tape.

required, it is applied to the outside of the finger grip by using the thumb and ring finger.

c. The tension handle (a scale which measures tensions in pounds) should be used by the front tapeman until both tapemen become accustomed to the "feel" of 25 pounds tension.

6–10. Use of Plumb Bobs

The tapemen use plumb bobs to project points on the tape to the ground. Each tapeman holds the plumb bob cord on the proper tape graduation with the thumb of one hand on the cord and the forefinger of that hand beneath the tape (fig 6–3). After alining the tape and applying tension to it, each tapeman lowers the plumb bob by letting the cord skip across the tape until the tip of the plumb bob is approximately one-fourth inch above the desired point. Swinging of the plumb bob is eliminated by gently lowering the tape until the plumb bob tip touches the ground and then slowly raising it.

a. The rear tapeman uses his plumb bob to position his end of the tape directly over the point from which each tape length is measured.

b. The front tapeman establishes the point on the ground to which each tape length is measured by dropping his plumb bob. After establishing the point with the plumb bob, the front tapeman marks the point with a taping pin. The rear tapeman can locate each pin more readily if the front tapeman clears the ground of grass, leaves, etc., or kicks a groove in the ground.

6–11. Use of Taping Pins

The tapeman must use the taping pins to mark points on the ground for each full or partial tape length. The front tapeman marks the point struck by the tip of the plumb bob by sticking the pin into the ground at exactly that point. The shaft of the pin should be placed on an angle of about 45° with the ground and perpendicular to the length of the tape. When moving forward, the tapeman should not pull the tape through the loop of the taping pin. When taping over a hard surface, it may be necessary to mark the point struck by the

plumb bob in an identifiable fashion (point of taping pin or pencil). The point of the pin should be laid at the point struck by the plumb bob, perpendicular to the line of direction of the tape.

6–12. Breaking Tape

When the tape cannot be alined within one-half meter (1½ ft) of a horizontal plane because of the slope of the ground, the tapemen use a special procedure known as breaking tape (fig 6–4). The procedure for breaking tape is as follows:

a. The front tapeman pulls the tape forward a full length, drops it approximately on line, and then comes back along the tape until he reaches a point at which a partial tape length, when held level, would be no higher than the armpits of the downslope tapeman. At this point, the front tapeman selects any convenient full meter graduation. The tapemen then measure the partial tape length, applying the full 25-pound tension to the tape. Clamping handles are used at any holding point between ends of the tape.

b. After he has placed the taping pin, the front tapeman waits until the rear tapeman comes forward. The front tapeman tells the rear tapeman which full meter graduation was used, e.g., HOLDING 25. The rear tapeman repeats HOLDING 25. The front tapeman *receives a pin from the rear tapeman* and moves forward, repeating this procedure until the zero mark on the tape is reached.

c. When holding a point on the tape other than the zero graduation, the front tapeman must receive a pin from the rear tapeman before moving forward.

6–13. Measuring Distances in Excess of 10 Tape Lengths

To measure a distance longer than 10 full tape lengths, the tapemen use the procedures discussed in paragraphs 6–5 through 6–12 except as follows:

a. When the front tapeman has set his last pin in the ground, he has established a point which is 10 full tape lengths from the rear station. The front tapeman waits at the last pin position until the rear tapeman comes forward.

b. Both tapemen count the pins to verify that none have been lost. (one pin is in the ground and is not counted; 10 pins should be in the possession of the rear tapeman.

c. The rear tapeman gives the front tapeman the 10 pins.

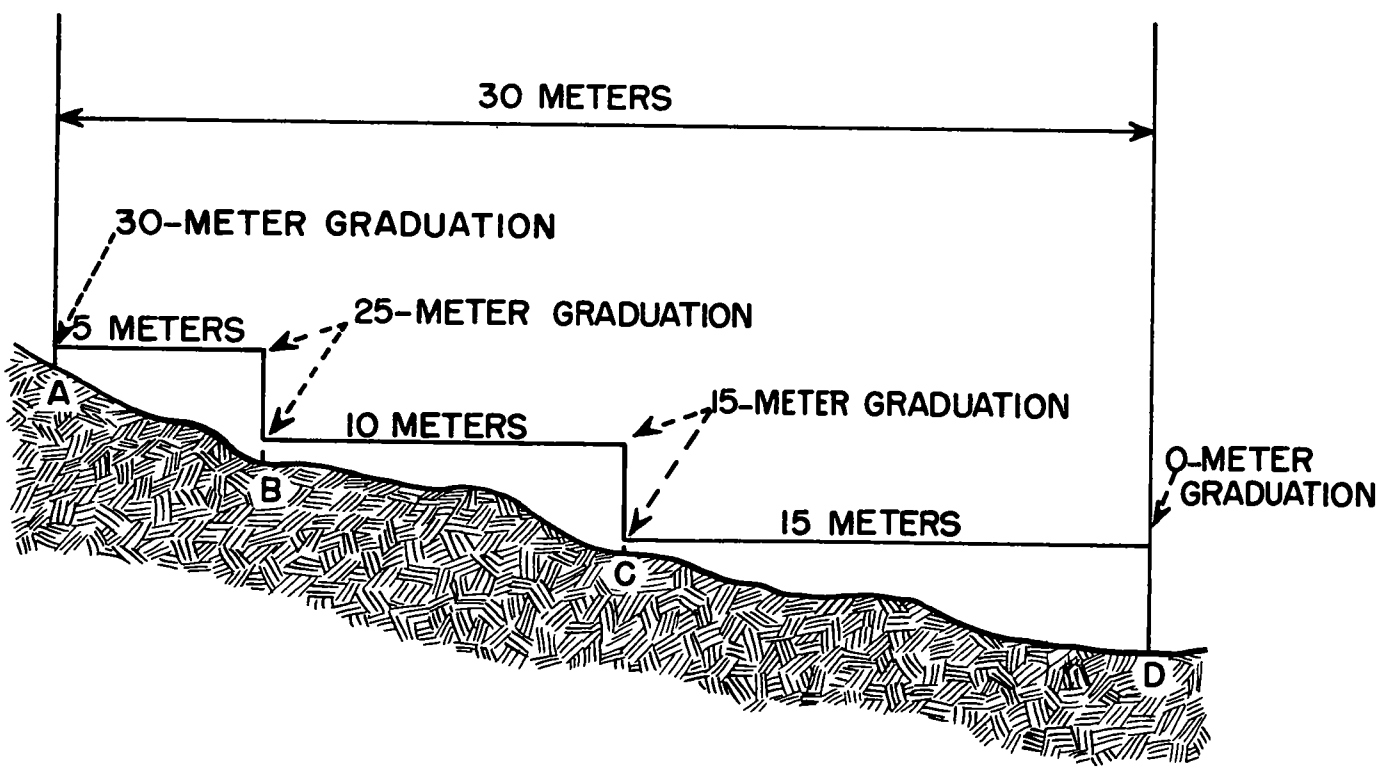


Figure 6–4. Breaking tape.

d. Both tapemen record 10 tape lengths (300 meters) and then continue taping.

6–14. Measuring Partial Tape Lengths

To measure the partial tape length between the forward station and the taping pin representing the last full tape length, the tapemen use the following procedure:

a. The front tapeman moves to the forward station and places the plumb bob cord on the zero graduation of the tape. The rear tapeman moves forward along the tape to the taping pin.

b. If slack is needed, the front tapeman commands SLACK and the rear tapeman allows the tape to move forward. When the front tapeman is ready he commands PULL and the rear tapeman exerts a pull of 25 pounds on the tape, using a clamping handle to hold the tape. As tension is applied to the tape, the rear tapeman slides his plumb bob cord along the tape until the plumb bob is exactly over the pin.

c. When the zero graduation is exactly over the forward station, the front tapeman commands READ. The rear tapeman reads the graduation marked by his plumb bob cord, and announces the measurement of the partial tape length to the nearest 0.01 meter.

d. The front tapeman repeats the reading aloud, and both tapemen record the measurement.

6–15. Taping at an Occupied Station

When a taping team is making a measurement at a station occupied by an instrument, the tapeman at the station must use extreme care not to disturb the instrument. If a plumb bob is used with the instrument, the tapeman can make his measurement at the plumb bob cord of the instrument.

6–16. Use of Two Taping Teams

When two taping teams are used to measure the distances between two stations, one taping team uses a pin to establish a starting station a half tape length (15 meters) from the rear station. In this case, the front tapeman does not give a pin to the rear tapeman. The taping pin marking the half tape length represents one full tape length plus 15 meters. After the starting station is established a half tape length from the rear station, the taping procedures are the same as those discussed in paragraphs 6–5 through 6–12, except that each tapeman adds 15 meters to the distance measurement. This procedure precludes both teams placing their taping pins in the same hole

6–17. Taping at Night

Daytime taping methods may be used at night with certain modifications. A piece of white cloth should be tied to each end of the tape to assist the tapemen in following and locating the tape. Three men should be added to each taping team. One man accompanies each tapeman as a light holder; the third man marks the taping pin with his light. When the rear tapeman comes to the taping pin, the third man walks the length of the tape, freeing it from any obstacles. This procedure is repeated for each full or partial tape length. The light holders must observe security precautions when using their lights.

6–18. Determining Taped Distance

The tapemen determine and check the distance measurement (fig 6–5), using the following procedures:

a. Each tapeman counts the number of pins in his possession. (The pin in the ground at the last full tape length is not counted.)

b. The rear tapeman determines the distance measurement by multiplying the length of the tape (30 meters) by the number of full tape lengths measured and adding the partial length read from the tape. (The number of full tape lengths measured is equal to 10 for each exchange of pins plus the number of taping pins in his possession.)

c. The front tapeman independently checks the distance measurement by multiplying the length of the tape by the number of full tape lengths measured and adding the partial tape length. (The number of full tape lengths measured is equal to 10 for each exchange of pins plus the difference between 10 and the number of pins in his possession.)

d. The rear tapeman reports the distance measurement to the recorder for entry in the field notebook.

6–19. Comparative Accuracy for Double-Taped Distances

a. When the distance between two stations has been determined by double-taping, the two measurements are compared and the comparative accuracy for the two measurements is determined. A comparative accuracy is expressed as a ratio

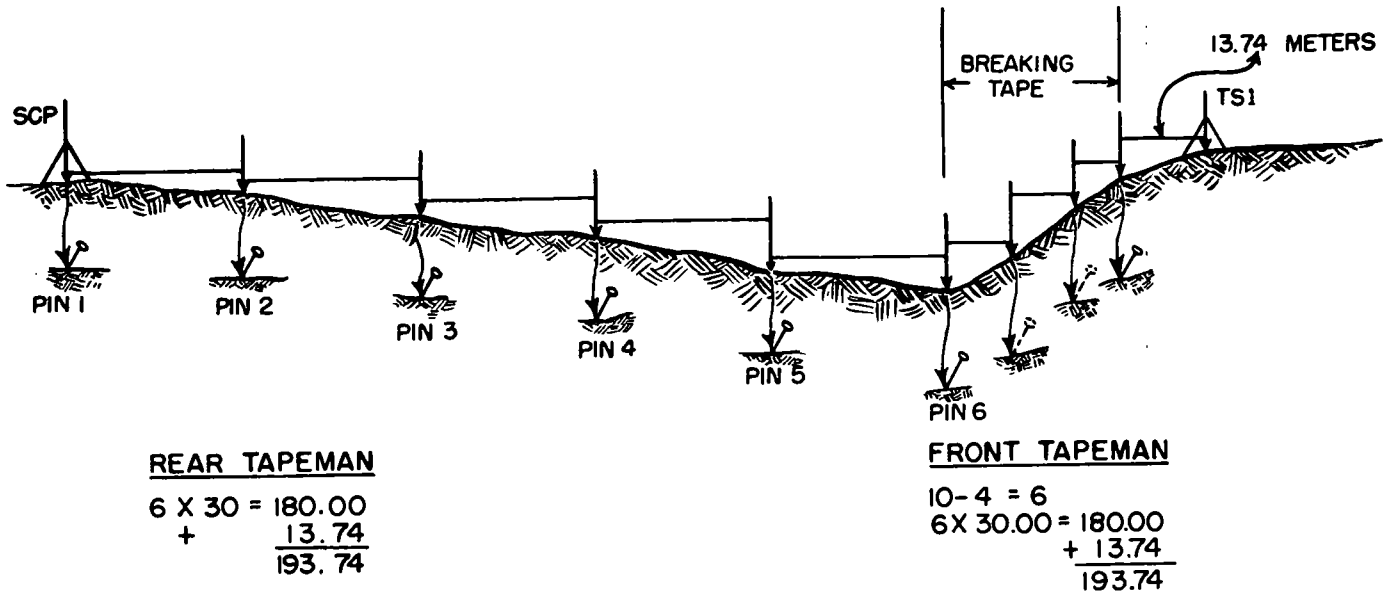


Figure 6-5. Determining taped distance.

between the difference in the measurements and the mean of the measurements. The radio is expressed with a numerator of 1, e.g., 1/1000 or 1:1,000. The denominator is determined by dividing the mean of the measurements by the difference in the measurements. After computing the comparative accuracy, the denominator of the fraction is always reduced to the next lower hundred.

b. The following example illustrates the computation of a comparative accuracy for a distance measurement:

Distance measurement by taping team 1 = 357.84 meters

Distance measurement by taping team 2 = 357.76 meters

Difference between measurements = 0.08 meter

Mean of the measurements = 357.80 meters

$$\text{Comparative accuracy} = \frac{\text{Difference}}{\text{mean}} = \frac{0.08}{357.80} = \frac{0.08 \div 0.08}{357.80 \div 0.08} = \frac{1}{357.80 \div 0.08} = \frac{1}{4472} \text{ or } \frac{1}{4400}$$

c. When the double-taped distance does not meet the required comparative accuracy, the distance must be taped a third time. The third measurement is then compared with each of the first two measurements to determine if a satisfactory comparative accuracy can be achieved with one or the other. The unsatisfactory distance is then discarded.

6-20. Taping Techniques and Specifications

To achieve the various degrees of accuracy in survey, distances must be determined accurately to within certain specifications, depending on the method of survey used. Taping techniques and prescribed accuracies for the different methods of survey are as follows:

a. Traverse.

(1) Fifth-order (1:1,000)—single-taped; checked by pacing.

(2) Fourth-order (1:3,000)—double-taped to a comparative accuracy of 1:5,000.

b. Triangulation, Intersection, and Resection.

(1) Fifth-order (1:1,000)—double taped to a comparative accuracy of 1:3,000.

(2) Fourth-order (1:3,000)—double-taped to a comparative accuracy of 1:7,000.

6-21. Errors in Horizontal Taping

Horizontal taping errors fall into three categories, as follows:

a. Systematic Errors. Systematic errors are errors which accumulate in the same direction. They can be measured and are normally constant in each tape length.

(1) The systematic errors encountered in horizontal taping cause distance to be measured longer or shorter than their true lengths. The principal causes of systematic errors are:

(*a*) Failure to aline the tape properly.

(*b*) Failure to apply sufficient tension to the tape.

(*c*) Kinks in the tape.

(*d*) Tape of incorrect length (a little short or a little long.)

(2) Systematic errors can be eliminated or minimized by strict adherence to proper procedures and techniques. Tapemen should be especially attentive to keeping the tape horizontal when taping on a slope and should break tape when necessary. They should avoid the tendency to hold the tape parallel to the slope. When taping in strong winds, tapemen must be especially careful to apply the proper tension to the tape. Tapes should be checked frequently for kinks. One of the chief causes for kinked tapes is improper use of the clamping handle.

(3) Systematic errors can be due to improper repair of the tape (repaired too long or too short), causing taped distances to be longer or shorter than their true distances.

b. Accidental Errors. Accidental errors are those errors which involve probability, and may accumulate in either direction. They are usually minor errors and tend to offset each other. The principal accidental error encountered in taping is caused by small errors in plumbing. Tapemen should be careful in plumbing over points, and when taping in strong winds they must be especially careful to minimize swinging of the plumb bob cord. This can be accomplished by keeping the plumb bob close to the ground and shielding the plumb bob as much as possible with the tapeman's leg.

c. Errors Caused by Blunders. Blunders are major errors made by poorly trained or careless personnel. A blunder may be an error in any direction and normally can be corrected only by remeasuring the distance.

(1) The principal blunders made by tapemen are—

(*a*) An incorrect exchange in taping pins.

(*b*) An error in reading the tape.

(*c*) An omission of the half tape length when double-taping with two teams.

(*d*) Loss of a taping pin.

(2) Blunders can be detected and eliminated by strict adherence to proper procedures and by adoption of a system of checks, e.g., by double-taping, by pacing each taped distance, and, in some cases, by plotting the grid coordinates of the stations on a large scale map.

Section II. TELLUROMETER MRA 1/CW/MV

6–22. General

The Tellurometer (MRAI) is an electronic distance-measuring device which may be issued to artillery units required to perform fourth-order survey (fig 6–6). The Tellurometer system consists basically of one master and two remote units. Additional items used to complete a Tellurometer measurement include the altimeter (when stations are not intervisible) and logarithmic tables. Distance is determined by measuring the loop transit time of radio microwaves from the master unit to the remote unit and back and converting one-half of this loop transit time to slope distance and then to sea-level distance. Optical line of sight *is not* required, but electrical line of sight between the instruments *is* required. The *minimum* range capability of the equipment is 152 meters, and the maximum rated capability is 64,000 meters (40 miles) under ideal conditions. Approximately 30 minutes is required to measure and compute a distance regardless of the length of the measurement. A distance can be measured during daylight or darkness and through fog, dust, or rain. A distance measurement with the Tellurometer is reduced to a sea level distance and is then used in the same manner as a taped distance.

6–23. Description of Components

a. The master unit and the remote units are similar in appearance (fig 6–7, 6–8, and 6–9) but neither the master nor the remote unit can be operated in a dual role because of the internal characteristics. The units have the same external dimensions (approximately 21 x 10 x 19 inches) and each weighs 28 pounds. Both units have parabolic reflectors, which are shown in the operating position in figure 6–9. The mirror surface of the reflectors radiates the received signal to the dipole. The dipole contains the transmitting and receiving antennas. Both units have identical built-in aerial and communication systems. A luggage-type handle facilitates carrying the instrument when it is removed from its case. The hinged door in the lower left corner of the control panel (fig

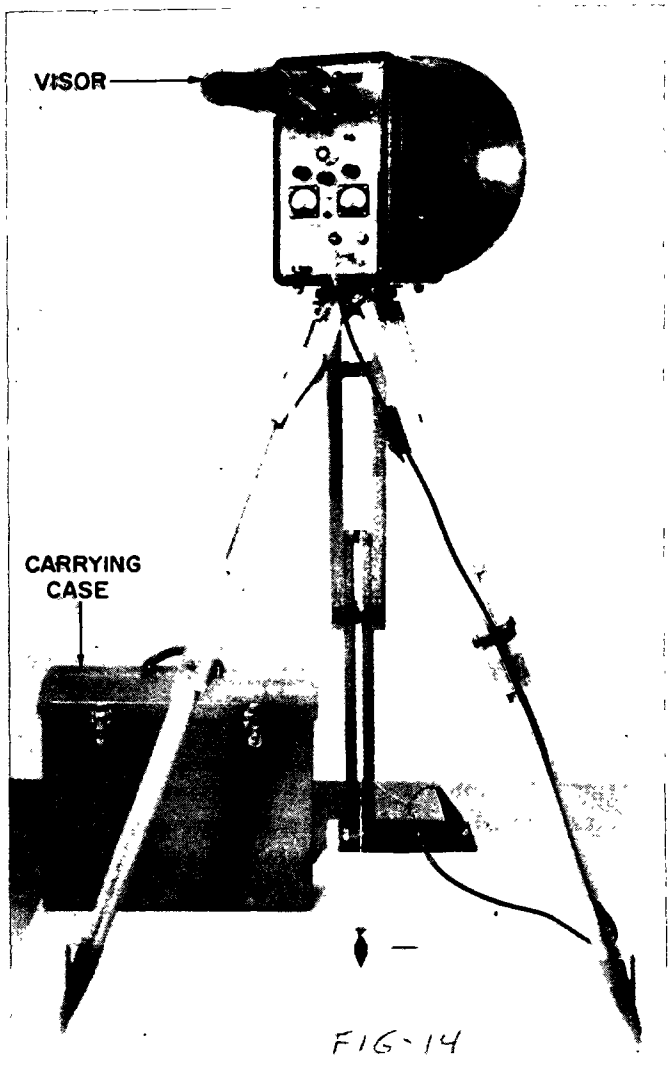


Figure 6-6. Tellurometer (MRA1) station with operating equipment and carrying case.

6-7 and 6-8) opens into a compartment in which the radiotelephone handset is stored. A cathode-ray tube (CRT) visor (fig 6-6) is mounted over the CRT scope during operation to shut out light and make scope presentations more clearly visible.

b. The carrying case (fig 6-6) is a lightweight, metal alloy, top-opening container, the lid is provided with a sponge rubber seal for protection against moisture. The case measures 22 x 12 x 22 inches and weighs approximately 18 pounds; it is fitted with a luggage-type handle for carrying. The case also has a back-strap device which permits the operator to carry it on his back. The case is fitted to hold the instrument (master or remote) in place, and compartments are provided in the case for spare parts, the CRT visor, a plumb bob, a plastic rain cover, and a container of silica gel.

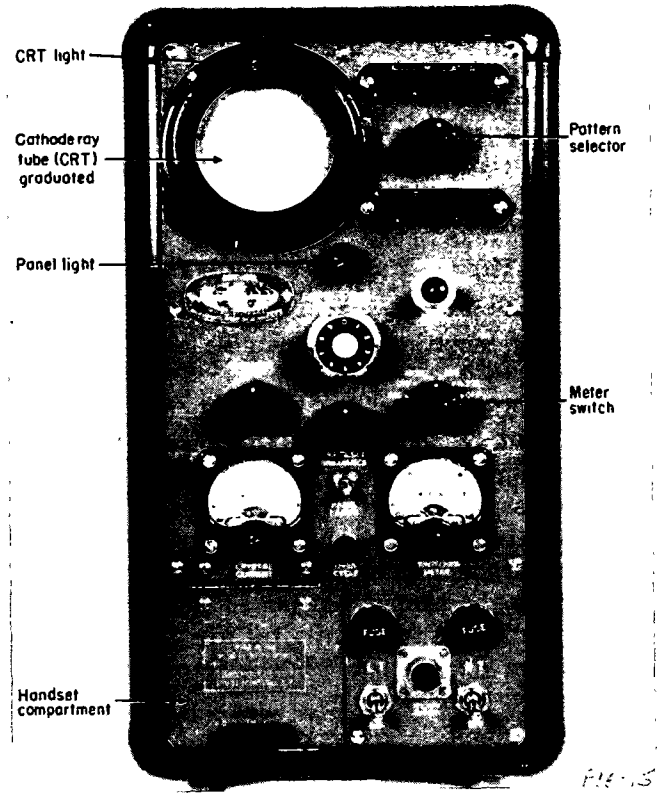


Figure 6-7. Control panel, master unit.

c. The universal tripod is issued with the Tellurometer; this tripod is interchangeable with the tripod used with the 0.2 mil and 0.002 mil theodolites.

d. Three different power sources may be used with the Tellurometer. A 12-volt, 40-ampere-hour battery or a 24-volt, 20-ampere-hour battery system may be cabled directly to a built-in powerpack (fig 6-7 and 6-8). In addition, either a 115-volt 60-cycle power supply or a 230-volt, 50-cycle power supply can be utilized by means of a mains converter. A fully charged battery will permit 4 to 6 hours of continuous operation. An 18-foot cable is provided so that the built-in powerpack can be connected to a vehicle battery for 24-volt operation.

e. The spare parts kit consists of a small metal box containing tubes, regulators, lamps, and fuzes. A list of these parts is provided in the metal container.

f. Additional accessories include a harness (backstraps) and pack, a CRT visor, a plastic rain cover, a screwdriver, a nonmetallic screwdriver, two power supply cables, a mains converter, a handbook (Operation and Maintenance), and the Preliminary Maintenance Support Manual.

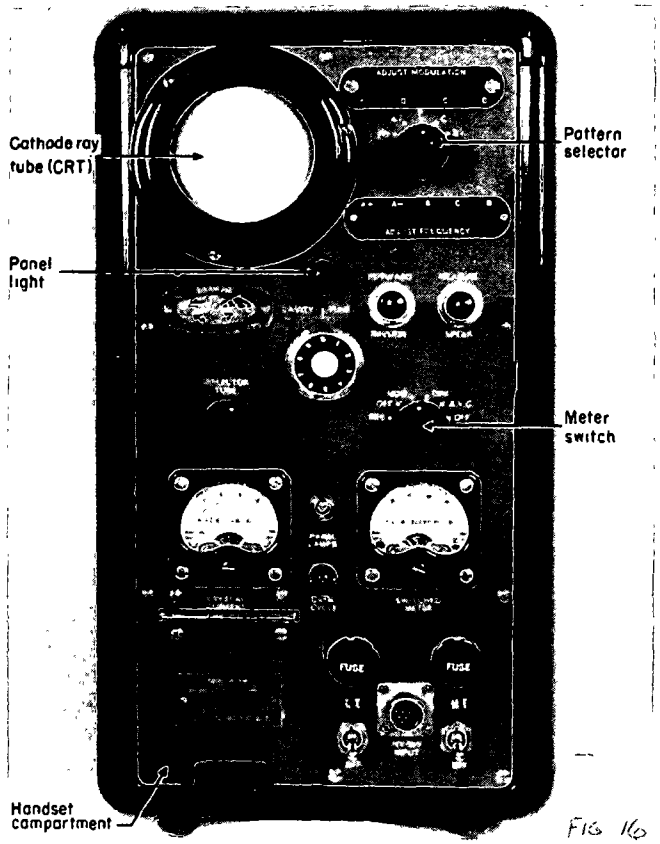


Figure 6–8. Control panel, remote unit.

g. A surveying altimeter, issued as a separate TOE line item, should be available with each master and remote unit for the determination of difference in height when it is not possible to measure the vertical angle between the master and remote units with a theodolite. The vertical angle or difference in height is necessary to convert the slope distance measured with the Tellurometer to horizontal distance.

6–24. Notekeeping

Field notes of the Tellurometer survey are entered on DA Form 5–139 (Field Record and Computations—Tellurometer). The computations for determining sea level distance are also accomplished on this form (fig 6–12). The completed form, with field records and computations, should be filed with the associate survey computations.

6–25. Principles of Operation

a. When the Tellurometer system is used to perform a distance measurement, one master unit and one remote unit must occupy opposite ends of the line to be measured. A continuous radio wave of 10-centimeter (cm) wavelength (3,000 megahertz is radiated from the master unit). This radio wave is modulated by what is referred to as pattern frequency. The modulated wave is received at the remote unit and in effect is reradiated from its transmitting system to the master unit.

b. At the master unit, the return wave is compared with the transmitted wave, and the phase comparison, or the difference in the two waves, is indicated on the circular sweep of the master unit cathode-ray tube (CRT) in the form of a small break, which marks the phase on a circular scale (fig 6–10). The circular scale (graticule) is mounted over the face of the CRT of the master unit and is divided into 10 major and 100 minor graduations. The leading edge of the break in the circular sweep is read clockwise to the smallest minor graduation. The *transit time*, the time required by the wave to travel from the master unit to the remote unit and back, is determined from a series of readings on the cathode-ray tube of the master unit.

6–26. Selection of Stations

Tellurometers are normally used for distance measurements in three types of survey; trilateration, traverse, and triangulation. Tellurometer measurements require an *electronic line of sight* which means the line between stations must be clear of large terrain features such as hills or dense foliage. For accurate results, the electronic line of sight should be free of terrain features such as large lakes, areas without vegetation, etc. (Trilateration requires the measurement of the sides of a closed figure but *does not* require the measurement of horizontal or vertical angles. Therefore, an *optical line of sight* is not necessary.) However, when the tellurometer is used in traverse, in which a theodolite is used to determine angles, optical line of sight between stations is necessary to measure the angles. The proper selection of stations for a theodolite will usually provide lines of sight for the tellurometer. The best site for a Tellurometer station is on top of a high peak. However, the following factors must also be considered because of the effects caused by the reflection of microwaves:

a. The ground between the two stations should be broken and, preferably, covered with trees and vegetation to absorb ground waves and prevent them from interfering with the direct signal.

b. When possible, the ground should slope gradually away from each instrument.

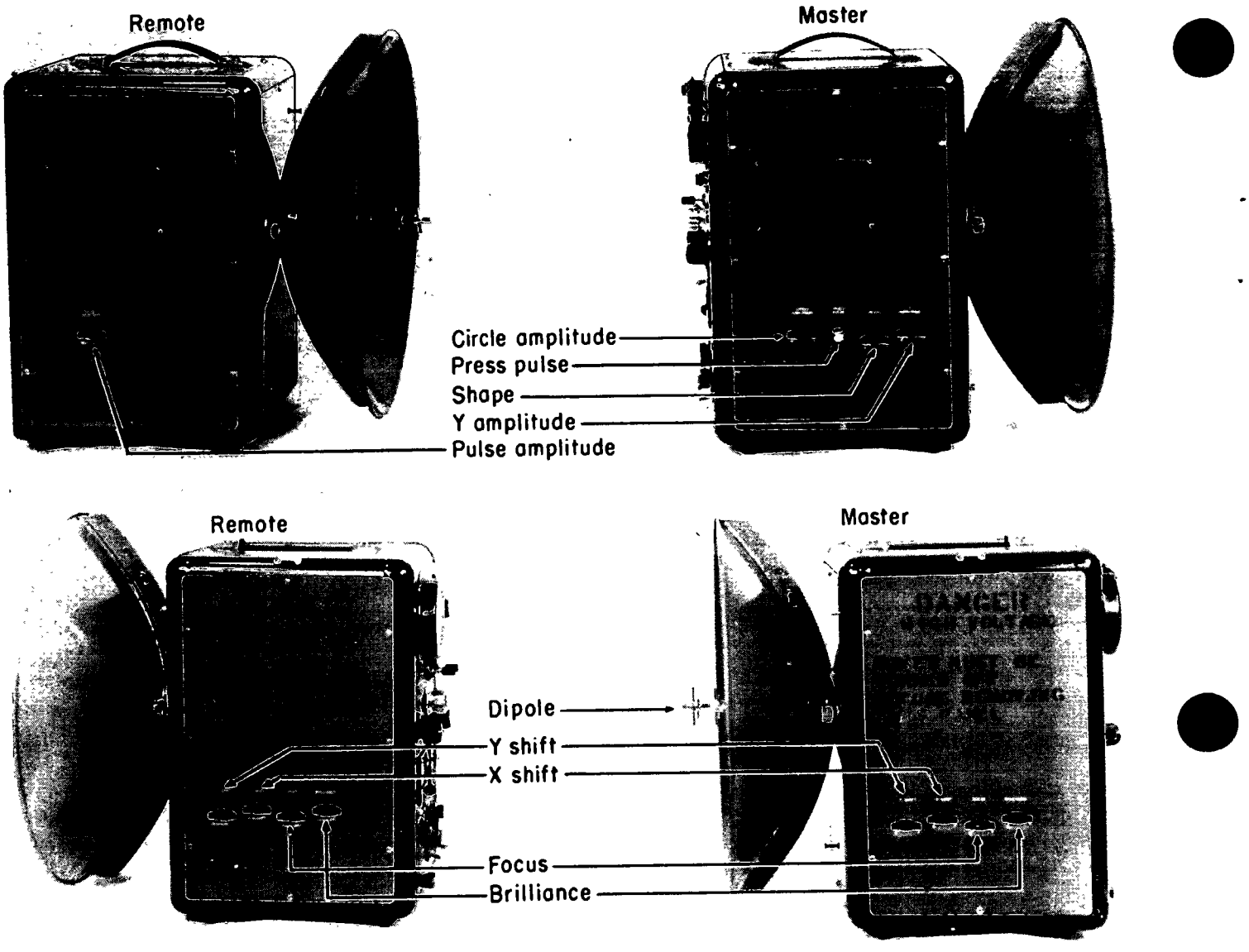


Figure 6–9. Side view of master and remote units.

c. If possible, measurements should not be made over highly reflective surfaces, such as smooth areas, desert sands, and water. Figure 6–11 illustrates the effect of the reflection of microwaves from water. An error, sometimes referred to as ground swing, is caused when the Tellurometer receives both the direct wave and the reflected wave. Some of the error is removed by the method of observing. The mean of the four fine readings, each at a different cavity tune setting, removes a part of the swing error.

d. The instruments should be set well back from the edge of the high land so that as much of the reflective area as possible becomes "dead ground" to the receiving instrument (fig 6–11).

e. The Tellurometer should not be operated across the path of any high-tension powerlines because this may result in erroneous readings. If wires cannot be avoided, a point may be established directly beneath the powerlines and readings made with no adverse effect. The Tellurometer should not be operated close to any other electronic equipment, such as radios and radars. This procedure will result in erroneous readings and possible damage to the set.

6–27. Instrument Controls

The controls for the operation of the master and remote units are classified into four functional groups—the *setting up controls*, used initially in

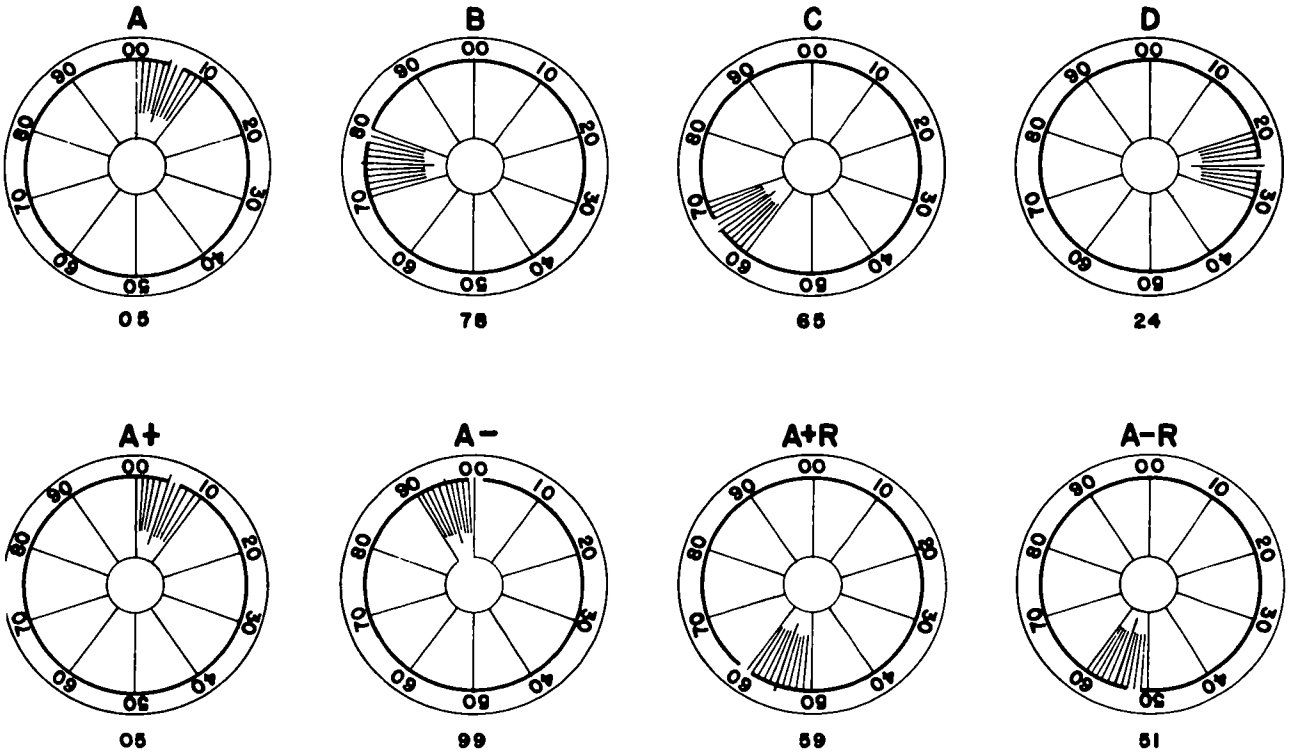


Figure 6-10. Cathode-ray tube pattern reading.

setting up the instruments and establishing a satisfactory cathode-ray tube presentation; the *operating controls,* used during the measurement; the monitoring controls, used to check circuit operation; and the *present controls,* which normally require no adjustment. Each of these functional groups includes a number of individual controls.

a. Setting Up Controls.

(1) The LT (LOW VOLTAGE) and the HT (HIGH VOLTAGE) switches are used to apply power to the master and remote units after they have been cabled to a power source. These switches are located in the lower portion of the control panel on the units.

(2) A BRILLIANCE control is located on the left side panel of each unit and is used to adjust the brightness of the presentation on the cathode-ray tube of each instrument.

(3) A FOCUS control is located on the left side panel of each unit and is adjusted in conjunction with the BRILLIANCE control until a bright, sharp trace appears on the cathode-ray tube.

(4) An X-SHIFT control is located on the left side panel of each unit, and it moves the trace in a horizontal direction across the face of the cathode-ray tube.

(5) A Y-SHIFT control is located on the left side panel of each unit, and it moves the trace in a vertical direction across the face of the cathode-ray tube.

(6) The CIRCLE AMPLITUDE control is located on the right side panel of the master unit and is used to adjust the diameter of the circular trace that is presented on the cathode-ray tube.

(7) The SHAPE control and the Y-AMPLITUDE control are located on the right side panel of the master unit and are adjusted together to achieve a circular trace on the cathode-ray tube.

b. Operating Controls.

(1) A PATTERN SELECTOR control is located in the upper part of the control panel of each unit and is used to select pattern A, B, C, or D, as required, during the measuring procedure. In addition, the PATTERN SELECTOR control on the remote unit selects the A+ or A— pattern upon instructions from the master unit operator.

(2) A MEASURE-SPEAK key is located in the center portion of the control panel of each unit and is used for switching from radiotelephone to measure and also for signaling during a measurement.

(3) A CAVITY TUNE dial is located in the center portion of the control panel of each unit and is used similarly to that of a program selector

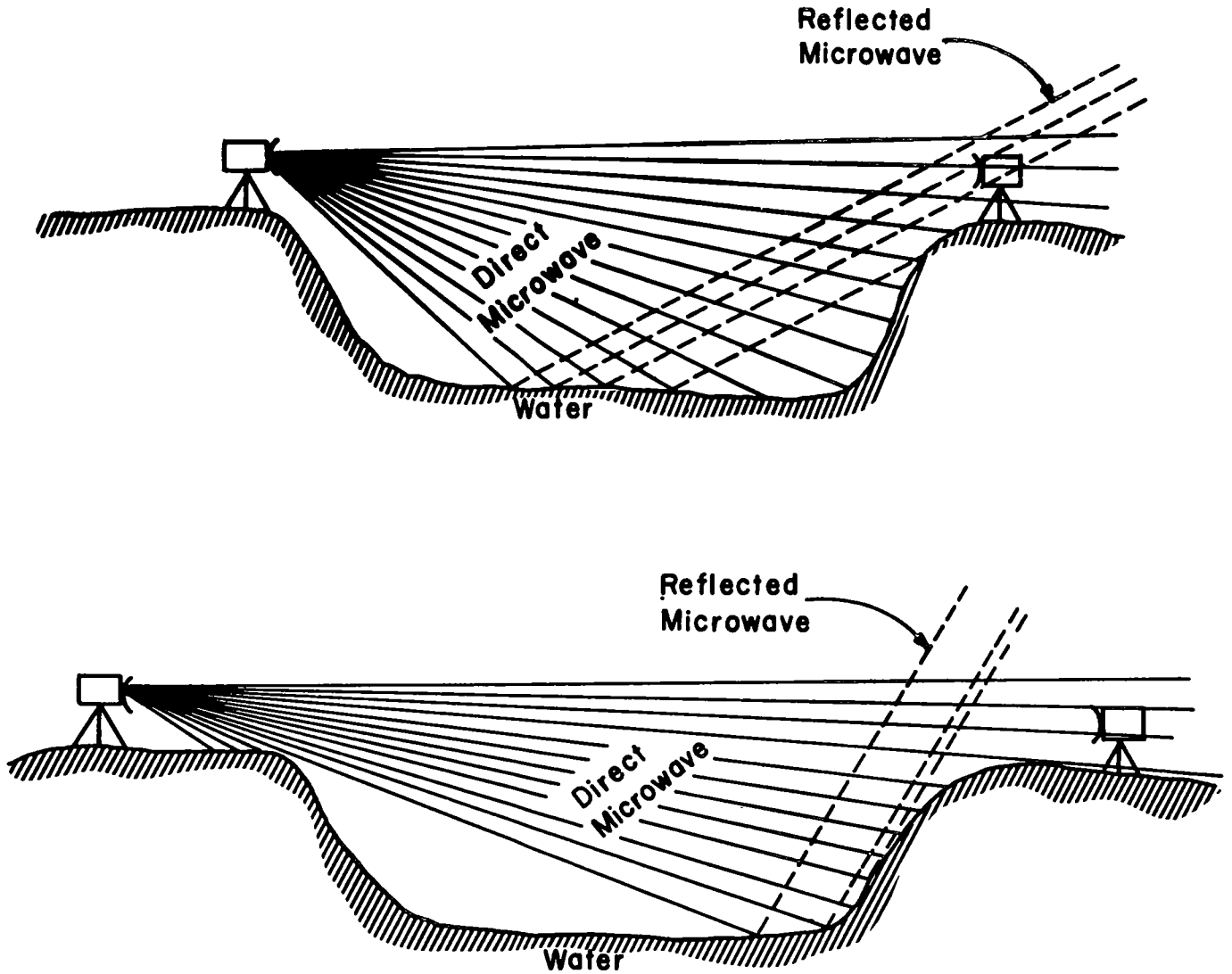


Figure 6-11. Reflected microwaves.

on a radio. Each CAVITY TUNE dial setting has a corresponding frequency.

(4) A REFLECTOR TUNE dial is located in the center portion of the control panel of each unit and is used for electrical tuning of the klystron. It should be adjusted at all times for maximum crystal current, which is indicated on the CRYSTAL CURRENT meter.

(5) The FORWARD-REVERSE reading key is located in the center portion of the control panel on the remote unit and is used to select the forward A+ or A— pattern of the reverse A+ or A— pattern, as instructed by the master unit opertor.

(6) The PULSE AMPLITUDE control is located on the right side panel of the remote unit and is used to adjust the amplitude of the pulse being returned by the remote unit to the master unit.

c. Monitoring Controls.

(1) The PRESS PULSE control is located on the right side panel of the master unit. It is used by the master unit operator to verify that a pulse of sufficient strength is being received from the remote unit. When the master unit operator presses the PRESS PULSE control, he is able to view on his cathode-ray tube the pulse pattern that is presented on the remote unit cathode-ray tube.

(2) A METER switch is located on the center portion of the control panel of each unit and is used in conjunction with the SWITCHED METER to check circuit operation. The switch is set to the REG position to check voltage regula-

tors in the klystron circuit. It also indicates the state of charge of the battery. In the MOD position, the meter reading indicates that circuit pattern modulation is taking place. In the AVC position, the meter indicates the strength of the received signal. (The REFLECTOR TUNE control should always be adjusted to obtain a maximum AVC reading.) The three remaining switch positions are OFF positions indicating that the SWITCHED METER (not the Tellurometer unit) is off.

(3) A CRYSTAL CURRENT meter is located in the center portion of the control panel of each unit and registers the crystal current. This reading should be kept at the maximum at all times by adjusting the REFLECTOR TUNE dial.

d. Preset Controls.

(1) The ADJUST MODULATION control plate located above the PATTERN SELECTOR switch on the control panel of each unit must be removed to adjust the modulation controls. A nonmetallic screwdriver is used to adjust the modulation level of pattern A, B, C, and D to read 40, 40, 40, and 36, respectively.

(2) The ADJUST FREQUENCY control plate located immediately below the PATTERN SELECTOR switch on the control panel of each unit must be removed to use the four controls for the adjustment of crystal frequencies. *This adjustment is performed only by a qualified technician.*

6–28. Setting Up the Tellurometer

The instructions contained in *a* through *k* below are applicable to both the master station and the remote station while measuring distances of more than 150 meters.

Note. Any attempt to operate a master unit and remote unit while they are pointing at each other at a distance of 150 meters (500 feet) or less will result in extensive damage to the units. If distances less than 150 meters *must* be measured and the terrain is such that taping is impossible, the Tellurometers may be pointed away from each other and the measurement made, however, accuracy will decrease.

a. Set up the tripod over the point which identifies one end of the line to be measured, using the procedure outlined for setting up the aiming circle (para 7–4).

b. Remove the instrument from the case and place it on the tripod head. Thread the tripod screw into the base of the instrument and tighten it to insure that the instrument is fixed to the tripod. Point the dipole in the approximate direction of the remove station. The Tellurometer radiates a conical beam of about 10°. In windy weather, the Tellurometer should be tied down so that it will not be blown over and damaged.

c. Dismount the parabolic reflector from its closed (travel) position and remount it in the open (operating) position, making sure that the fasteners fit properly and snugly. Failure to do so may result in damage to the unit.

d. Remove the power supply cable and the telephone handset from the storage compartment under the control panel. Hang the telephone handset on an improvised hook or bracket on the tripod. Never place the handset on top of the unit, because inaccuracies are created if the handset is left there during the measurement. *Place the LT and the HT switches in the OFF position.*

e. When a 12-volt battery is used, connect one end of the *short* (8-foot) 12-volt power supply cable to the INPUT receptacle on the control panel, and the other end to the battery. Connect the *red lead* to the *positive post* and the *black lead* to the *negative post.*

f. When a 24-volt battery is used, connect one end of the *long* (18-foot) 24-volt power supply cable to the INPUT receptacle on the control panel, and the other end of the battery. Connect the *red lead* to the *positive post* and the *black lead* to the *negative post. Do not use the short 12-volt power supply cable with a 24-volt battery,* because this will damage the unit.

g. The system is ready to be turned on after the completion of either *e* or *f* above. Place the LT switch in the ON (up) position. This provides a filament current to the tubes in the instrument. *It must be turned on 30 seconds before turning on the HT switch.* Both the LT and HT switches must be in the ON position for operation of the instrument. The HT switch should be in the OFF position while waiting for the prearranged time of operation agreed upon by the master and remote operators.

h. Turn the METER switch to the REG (voltage regulator) position and the MEASURE-SPEAK key to MEASURE. The reading on the SWITCHED METER will vary with the strength of the battery. The reading should be at least 30 to permit a satisfactory measurement. A reading of less than 30 indicates that the charge in the battery is too low for operation.

i. Adjust the REFLECTOR TUNE dial for maximum crystal current. The CRYSTAL CURRENT dial should read above 0.2 for best operation. The lowest reading on the CAVITY TUNE dial will usually give the greatest CRYSTAL CURRENT reading.

j. Turn the METER switch to MOD (modulate) position and check the modulation level of each crystal. The PATTERN SELECTOR must be turned to each crystal, in turn. The correct readings, as viewed on the SWITCHED METER, should be 40 on A, B, and C and 36 on D. If these readings are not approximated, remove the ADJUST MODULATION cover and adjust the modulation trimmers. The trimmers should be adjusted if the reading varies ±2 from 40 or 36, depending on the crystal being checked. A nonmagnetic screwdriver should be used for this adjustment.

k. Switch the MEASURE-SPEAK key to SPEAK and move the METER switch to AVC position. The SWITCHED METER should read about 20 microamperes without the two instruments being tuned and without the other set being turned on. Turn the REFLECTOR TUNE dial. If the SWITCHED METER needle moves, the receiver is working. If there is no movement of the indicator, trouble can be suspected in the receiver and a repairman should be consulted.

l. This step is performed by the master unit only. Switch the MEASURE-SPEAK key to SPEAK. There should be a spot of light near the center of the cathode-ray tube. Turn the CIRCLE AMPLITUDE control (right side panel) to make this spot as small as possible. Adjust the BRILLIANCE and FOCUS controls (left side panel) for a clear sharp spot. Center the spot carefully in the graticule, using the X-SHIFT and Y-SHIFT controls (left side panel).

m. While the master unit operator is completing the adjustment in *l* above, the remote unit, with the MEASURE-SPEAK key in the SPEAK position, should present a spot of light near the center of the cathode-ray tube. If necessary, adjust the BRILLIANCE and FOCUS controls for a clear, sharp spot and center the spot in the cathode-ray tube by using the X-SHIFT and Y-SHIFT controls.

6–29. Tuning Procedures

The instrument tuning procedures follow the setting-up procedures and must be completed before a measurement is made. These procedures start with the MEASURE-SPEAK key in the SPEAK position and require coordination between the master unit and the remote unit operators. For this reason, the following instructions are arranged to insure that the proper sequence is followed. In each step, the operation designated with the number 1 precedes the operation designated with the number 2.

Master unit operator	*Remote unit operator*
a1. Set the CAVITY TUNE dial two or three numbers below the previously agreed upon starting number (setting of remote). Place the METER switch in the AVC position. Increase the CAVITY TUNE dial setting until a maximum reading is indicated on the SWITCHED METER. A maximum AVC reading at this point indicates that the master instrument is tuned to the remote instrument.	a2. Set the CAVITY TUNE dial on the previously agreed upon starting number. Verify the maximum CRYSTAL CURRENT by using the REFLECTOR TUNE dial. Place the METER switch in the AVC position and watch the SWITCHED METER for a maximum reading as a signal that the master operator has tuned his set.
b1. Establish communications with remote operator.	b2. Answer the master operator's call.
c1. Direction find (DF) the instrument by traversing it on the tripod until the SWITCHED METER shows a maximum AVC reading. Check plumb after DF. Instruct the remote operator to direction find his instrument.	c2. When instructed to do so, direction find the instrument by traversing it on the tripod until the SWITCHED METER shows a maximum AVC reading. Check plumb after DF.
d1. Switch to MEASURE and turn the METER switch to the MOD position. Check modulation levels by turning the PATTERN SELECTOR to A, B, C, and D, in turn. Announce each modulation reading to the recorder for entry in block VI of the Field Record and Computations—Tellurometer (DA Form 5–139) (fig 6–12). Request modulation readings from the remote operator and announce these to the recorder for appropriate entry on the field record and computations form. Turn the METER switch to the AVC position.	d2. Switch to MEASURE and turn the METER switch to the MOD position. Check the modulation levels bu turning the PATTERN SELECTOR to A, B, C, and D, in turn. Note the values of the modulation levels. When requested to do so, report the modulation readings to the master operator.

Master unit operator	*Remote unit operator*
e1. Announce the following information to the recorder for entry in block I of the field record and computations form (fig 6–12): instrument numbers, station numbers, weather conditions, and operators' names.	e2. Stand by. If requested to do so, provide information to the master operator.
f1. With the MEASURE-SPEAK key at MEASURE, adjust the CRT circle to a convenient reading size by using the CIRCLE AMPLITUDE, Y-AMPLITUDE, and SHAPE controls.	f2. Switch the MEASURE-SPEAK key to MEASURE and stand by.
g1. Verify the maximum CRYSTAL CURRENT reading by turning the REFLECTOR TUNE dial. With the METER switch in the AVC position, readjust the CAVITY TUNE for a maximum AVC reading on the SWITCHED METER. Inspect the circular trace on the CRT for a good clean break. If a good break cannot be obtained or the pulse appears too weak or too strong, instruct the remote unit operator to adjust the PULSE AMPLITUDE.	g2. If requested to do so, adjust the PULSE AMPLITUDE.
Note. The Tellurometer system is now ready for distance measuring.	

6–30. Operating Temperature

a. The Tellurometer is designed to operate in temperatures ranging from —40°F to +104° F (manufacturer's estimate). The crystals of both the master and remote units are mounted in an oven which automatically maintains operating temperature. The operation of the oven begins as soon as the power source is connected, regardless of whether the LT or the HT is on or off.

b. Readings should not be taken until the OVEN CYCLE lamp has gone off for the first time. The OVEN CYCLE lamp will then blink on and off while automatically maintaining operating temperature.

c. Approximately 30 minutes is required for the crystals to reach operating temperature at —40°F air temperature; less than 15 minutes is required at +25° F air temperature. If the Tellurometer is operated in cold, extremely windy weather a light windbreak around the instrument will reduce warmup time.

6–31. Measurement Procedure

A Tellurometer measurement consists of one set of initial coarse readings, four sets of fine readings, and one set of final coarse readings. The readings are taken in this order and are recorded on the field record and computations form (fig 6–12) as they are taken. The completed form constitutes a record of the distance measured and the system operation during one measurement. This form should be retained to make up a permanent log for the operation of the system.

A coarse reading consists of readings on the A+, A—, B, C, and D patterns in that order. A fine reading consists of A+ forward, A— forward, A— reverse, and A+ reverse pattern readings taken in that order for convenience in switching. If both operators know and follow this sequence for reading the patterns, the need for radiotelephone conversation will be reduced. As the reading in each pattern is completed, the master unit operator signals for a change to the next crystal setting by depressing the MEASURE-SPEAK key twice. This signal can be detected on the remote unit CRT by a change in the presentation and can be heard on the remote unit radiotelephone as a break in the measuring tone. All readings are made at the master unit and are read in a clockwise direction at the leading edge of the break. For one complete set of readings, all of the patterns should be read without moving the CAVITY TUNE dial. If any adjustment is necessary to improve the circle break, it should be made with the REFLECTOR TUNE knob in conjunction with the PRESS PULSE sequence discussed in paragraph 6–29*g*. If a good break does not appear at this time, the leading edge of the flexing point (fig 6–14) on the circle may be used to determine a reading. The REFLECTOR TUNE knob and the CAVITY TUNE dial should be tuned simultaneously to maintain maximum AVC and CRYSTAL CURRENT readings between sets. The measuring procedures require coordination between the operators of the master and the remote units. In each step, the operation designated with the number 1 precedes the operation designated with the number 2.

FIELD RECORD AND COMPUTATIONS - TELLUROMETER

For use of this form, see TM 5-232; the proponent agency is U.S. Continental Army Command.

BLOCK I - STATION DATA

STATION		HEIGHT METERS	INST. NO.	OPERATOR	WEATHER: CLEAR - WARM	
MASTER: STERLING	1	449.1	238	LECLAIR	RECORDER: BURK	
REMOTE: APACHE	2	412.6	239	POLLARD	APPROX. DIS.: MILES 2.3	METERS 3500
3 HEIGHT DIFF: (1) & (2) 36.5		4 SUM OF HEIGHTS (1)+(2) 861.7			5 MEAN HEIGHT (4) ÷ (2) 430.8M	

BLOCK II - INITIAL COARSE READINGS

A+	05	A+	05	A+	05	A+	05
B	78	C	65	D	24	A−	99
DIFF	27	DIFF	40	DIFF	81	DIFF	06 / 2
COMPARE WITH A+							03.0

BLOCK III - FINE READINGS

SET	REMOTE DIAL	A	FORWARD	REVERSE	MEAN DIFF
1		+	05	59	
	3	−	99	51	
		DIFF	06	08	14 / 7.0
2		+	09	57	
	5	−	02	50	
		DIFF	07	07	14 / 7.0
3		+	08	56	
	7	−	03	51	
		DIFF	05	05	10 / 5.0
4		+	07	59	
	9	−	99	50	
		DIFF	08	09	17 / 8.5
SUM MEAN DIFF					27.5
DIVIDE BY NUMBER OF SETS TIMES 2					03.44
MEAN FINE READING (COMPARE WITH A+)					03.44

BLOCK IV - FINAL COARSE READINGS

A+	07	A+	07	A+	07	A+	07
B	79	C	66	D	25	A−	99
DIFF	28	DIFF	41	DIFF	82	DIFF	08 / 2
COMPARE WITH A+							04.0

BLOCK V - TRANSIT TIME (*III, IV & X*)

APPROX DIS MILES (X)	0	0	0	0	0	0	0	0
FINAL / COARSE / READING — A+,B DIFF		2	8	0	0	0	0	0
A+,C DIFF			4	1	0	0	0	0
A+,D DIFF				8	2	0	0	0
MEAN FINE READING III					0	3	4	4
BRING DOWN UNRESOLVED TRANSIT TIME	0	2	4	8	0	3	4	4
RESOLVED TRANSIT TIME	0	2	3	8	0	3	4	4

BLOCK VI - METER READINGS

		MASTER		REMOTE
AVC		50		48
REGULATOR		50		55
MODULATION	A	40	A	40
	B	39	B	40
LEVELS	C	41	C	39
	D	36	D	36

BLOCK VII - SLOPE DISTANCE, METERS

1	LOG CORRECTED TRANSIT TIME (V)	4	376	6397
2	LOG 1/2 V/N METERS	9	175	6509
3	LOG SLOPE DISTANCE METERS (1)+(2)	3	552	2906

BLOCK VIII - VERTICAL ANGLE

SLOPE DISTANCE (METERS) / VERTICAL ANGLE / HORIZONTAL DISTANCE (METERS) — DIFFERENCE IN HEIGHT (METERS)

1	DIFFERENCE HEIGHT METERS		36	5
2	LOG (1)	1	562	2929
3	LOG SLOPE DISTANCE METERS (VII)	3	552	2906
4	(2)−(3) LOG SIN VERT ANGLE	8	010	0023
5	VERTICAL ANGLE EQUAL TO LOG SIN (4)	°	10′	42″

BLOCK IX - SEA LEVEL DISTANCE METERS

1	LOG SLOPE DISTANCE METERS (VII)	3	552	2906
2	LOG COS VERTICAL ANGLE (VIII)	9	999	9773
3	(1)+(2) LOG HORIZONTAL DISTANCE METERS	3	552	2679
4	LOG SEA LEVEL COEFFICIENT (XI)	9	999	9727
5	(3)+(4) LOG SEA LEVEL DISTANCE METERS	3	552	2406
6	SEA LEVEL DISTANCE METERS			3566.49

BLOCK X - FIRST FIGURE (*TRANSIT TIME*)

APPROX DISTANCE MILES (I)	FIRST FIGURE
(0-10)	(0)
10 −20	1
20−30	2
30-40	3

COMPUTER	KEUTHAN	CHECKER	BLOXOM	SHEET 1 OF 1	SHEETS
NOTEBOOK REFERENCE	2-A	AREA	Eastern, Oklahoma	DATE	17 Apr. 67

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Figure 6-12. Field record and computations form.

BLOCK XI - SEA LEVEL COEFFICIENT

The height used to determine log sea level coefficient is height of known station to the nearest 100 meters. Mean height should be used if the heights of both stations are known.

HEIGHT METERS	LOG SEA LEVEL COEFFICIENT
-100	0.0000068
-50	0.0000034
00	0.0000000
50	9.9999966
100	9.9999931
200	9.9999863
300	9.9999795
400	9.9999727
500	9.9999659
600	9.9999590
700	9.9999522
800	9.9999453
900	9.9999386
1000	9.9999317
1100	9.9999249
1200	9.9999181
1300	9.9999112
1400	9.9999044
1500	9.9998976
1600	9.9998908
1700	9.9998839
1800	9.9998770
1900	9.9998703
2000	9.9998634
2100	9.9998566
2200	9.9998498
2300	9.9998429
2400	9.9998361
2500	9.9998292
2600	9.9998225
2700	9.9998156
2800	9.9998088
2900	9.9998020
3000	9.9997951
3100	9.9997883
3200	9.9997815
3300	9.9997747
3400	9.9997678
3500	9.9997609
3600	9.9997542

NOTE:

The above values were computed for a northing of 3 200 000 and azimuth of 45 degrees and can be used anywhere on the UTM grid without causing an error greater than 1:250,000.

GIVEN:

Height of station - METERS.

FIELD DATA:

a. Approximate distance in both miles and meters.
b. Corrected transit time.
c. Height if not available.
d. Vertical angle *(compute if not possible to measure).*

GUIDE:

a. BLOCKS II, III & IV - If A+ is less than B, C or A–, add 100 to A+ before determining the difference.
b. BLOCKS II, III & IV - "Compare with A+" means that this figure must compare ± 4 MUS with A+ in the final coarse reading. If necessary add 50.
c. BLOCK VIII*(5)* - Measured or computed vertical angle.

LIMITATIONS:

This form may be used for obtaining artillery survey accuracies.

RESULTS:

A sea level distance is determined which should be treated the same as a taped distance.

GPO 897312

Figure 6–13. Back of field record and computations form.

Master unit operator

a1. Switch to SPEAK and advise the remote operator that the initial coarse reading will be taken in the prescribed order (A+, A—, B, C, D). Switch to MEASURE, turn the PATTERN SELECTOR to position A, and read the value of the CRT to the nearest division (fig 6–10). Announce the value to the recorder for entry in block II of the field record and computations form (fig 6–12).

Flick the MEASURE-SPEAK key twice to indicate to the remote unit operator that the reading of the A+ pattern is complete and that a reading is desired on the next (A—) pattern.

When the A— pattern appears on the CRT, read the value and announce it to the recorder for entry in block II of the field record and computations form.

For the A— pattern, continue to read the clockwise edge of the break.

Flick the MEASURE-SPEAK key twice to indicate to the remote unit operator that the reading of the A— pattern is complete and that a reading is desired on the next (B) position.

Turn the PATTERN SELECTOR to position B and proceed as with the previous readings. After each reading, flick the switch to indicate readiness to read the next pattern.

When the C and D pattern readings have been completed, return the PATTERN SELECTOR to position A. This completes the initial coarse readings.

Remote unit operator

a2. When instructed that the initial coarse readings will start, switch to MEASURE. Each time the master unit operator signals to the next pattern frequency.

The master unit operator's signal will appear as a flick on the remote unit CRT and as a break in the measuring tone on the radiotelephone.

b1. Switch to SPEAK and advise the remote unit operator that each fine reading will be taken in the prescribed order (A+, A—, A— reverse, A+ reverse).

Normally four sets of fine readings are taken. The frequency interval between sets should be the maximum allowable (i.e., 3, 5, 7 and 9) over the range of the CAVITY TUNE dial. When making the reverse readings, continue to read the clockwise leading edge of the break.

Announce to the remote unit operator the remainder of the CAVITY TUNE dial settings.

b2. Switch to SPEAK and wait for instructions.

When advised that fine readings will be taken, turn the METER switch to the AVC position and set the CAVITY TUNE dial to the announced setting.

The CAVITY TUNE dial setting should be the same as that on which the initial course readings were taken.

c1. Adjust the CAVITY TUNE dial, if necessary, for maximum AVC readings. Check the REFLECTOR TUNE dial for maximum CRYSTAL CURRENT. Announce MEASURE to the remote unit operator and switch to MEASURE.

Check the circle sweep for focus, brilliance, size, shape, and circle break. If the circle break is not apparent, adjust it with the REFLECTOR TUNE dial and PRESS PULSE. If the adjustment fails to produce a break, communicate with the remote unit operator and request a high PULSE AMPLITUDE setting.

c2. Whn instructed to do so, increase or decrease the PULSE AMPLITUDE. On instructions from the master operator, switch the MEASURE-SPEAK key to MEASURE.

d1. Take the four sets of fine readings at the previously announced CAVITY TUNE dial intervals. Flick the MEASURE-SPEAK key to signal the remote unit operator.

Announce the value read for each pattern during the measurement of each set to the recorder for entry in block III of the field record and computations form (fig 6–12).

After taking the A+ reverse reading of each set, the master unit operator should pause momentarily before proceeding and allow the recorder to check the recorded values for possible reading errors.

d2. For each of the four sets of fine readings, use the following procedures:

When signaled by the master unit operator that the A+ reading is complete, switch the PATTERN SELECTOR to the A— position. On the second signal from the master unit operator, depress the FORWARD-REVERSE key. When the FORWARD-REVERSE key is in the REVERSE position, the master unit operator reads the A— reverse pattern. On the third signal, switch the PATTERN SELECTOR to the A+ position. This presents the A+ reverse pattern to the master unit operator. On the fourth signal, raise the FORWARD-REVERSE key and wait for instructions. When instructed to do so, switch to SPEAK and advance the CAVITY TUNE dial to the next setting.

Master unit operator	*Remote unit operator*
e1. Repeat the procedures in c1 and d1 above with different CAVITY TUNE dial settings for the required number (four) of sets of fine readings.	e2. Follow instructions from the master operator as indicated in c2 and d2 above.
f1. Switch to SPEAK and advise the remote unit operator that final coarse readings will be taken. Follow the procedure in a1 above at the last CAVITY TUNE dial setting. As the readings are made, announce the values to the recorder for entry in block IV of the field record and computations form (fig 6–12).	f2. Follow the procedure in a2 above at the last CAVITY TUNE dial setting.
g1. Compare the interpreted initial and final coarse readings for agreement (blocks II and IV of the field record and computations form). If a significant disagreement is evident (para 6–35), take additional coarse readings until the error is isolated.	
h1. Advise the remote unit operator that the measurement is complete and give further instructions. Instructions must be explicit and thoroughly understood, since at this point the instruments will be turned off and communication severed.	h1. Proceed as instructed.
If at any time in tuning a new CAVITY TUNE dial setting communications cannot be made with the remote unit, return to the last CAVITY TUNE dial setting at which contact was made and issue instructions.	If at any time in tuning to a new CAVITY TUNE dial setting communications cannot be made with the remote unit, return to the last CAVITY TUNE dial setting at which contact was made and await instructions.

6–32. Computing a Tellurometer Distance Measurement

a. Computations required for a Tellurometer distance measurement are performed on DA Form 5–139 in the following order:

(1) Interpret the initial coarse readings.

(2) Interpret the fine readings.

(3) Interpret the final coarse readings.

(4) Resolve the transit time in millimicroseconds from correctly interpreted pattern differences.

(5) Compute the slope distance in meters from a transit time in millimicroseconds.

(6) Reduce the slope distance to a horizontal sea level distance in meters.

b. Tellurometer distance measurements are normally computed at the master station before party personnel depart for subsequent survey operations. This permits the verification of the distance determined by map scaling and the resolution of ambiguous pattern differences if they occur. The distance scaled from a map will also provide the first digit of the transit time, which is a function of the distance in units of 10 miles. The first figure of the transit time is determined in block X of the field record and computations form and is entered in block V. Figure 6–12 illustrates a record of a distance measurement and is used as a reference for the discussion on computations in paragraph 6–33 through 6–39.

6–33. Interpreting the Initial Coarse Readings (Blocks II)

a. The phase difference is determined by subtracting the coarse readings B, C, D, and A— from the A+ reading. If the A+ reading is smaller than the B, C, D, and A— readings, as in figure 6–12, 100 is added to the A+ reading before subtracting.

b. The difference between A+ and A— is divided by 2 and the result is compared with the A+ reading; 50 is added to the result, if necessary, to keep it at approximately the same value as the original A+ reading. If the values do not compare within 4 millimicroseconds, the coarse measurements must be reobserved. In figure 6–12, this value (03.0) is within 2 millimicroseconds of the A+ reading (05), which is satisfactory.

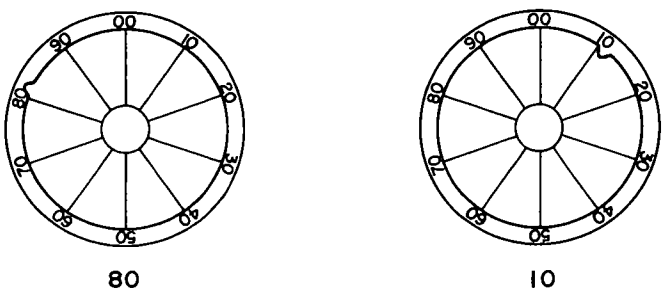


Figure 6–14. MASTER CRT showing flexing point on circular trace.

6-34. Iterpreting the Fine Readings (Block III)

After the fine readings are taken and recorded in block III, the mean differences and the mean fine reading are computed. In the example below, one set of the fine readings in figure 6-12, block III, is meaned:

Set	*Remote dial*	*Forward*	*Reverse*
1		A+ 05	A+ 59
	3	A- 99	A- 51
		06	08

06 + 08 = 14 ÷ 2 = 07 mean difference
07 ÷ 2 = 3.50 mean fine reading
A+ (initial coarse) = 05.00 (block II)
Mean fine reading = 03.50
Zeroing error = 1.50 millimicroseconds

a. In the *forward readings*, the A— is subtracted from the A+. Because the A+ is smaller than the A—, it is necessary to add 100 to 05 before subtracting (100 + 05 = 105; 105— 99 = 06). The 100 is added to A+ only when it is smaller than A—.

b. In the *reverse readings*, the A— is subtracted from the A+ (59 —51 =08). If the A+ is smaller than the A—, it is necessary to add 100 to the A+ before subtracting.

c. The difference in the forward readings is added to the difference in the reverse readings, and the sum is divided by 2 to obtain the mean difference (06 + 08 = 14 ÷ 2 = 07).

d. The mean difference is divided by 2 to obtain the mean fine reading (07 ÷ 2 = 3.50).

e. The procedure in *a* through *d* above is used to correct for the zeroing error at the remote dial setting of 3. Essentially the same procedure is used for the readings taken at the remote dial settings of 5, 7, and 9, except that, in block III of the form, the sum of the mean differences for the four dial settings is divided by 2 times the number of sets taken to determine the mean fine reading for all of the sets. This mean fine reading is computed (to the nearest hundredth) and compared with the initial A+ reading in block II. The difference in the two values (adding 50 to the mean fine reading if necessary) should compare within 4 millimicroseconds. If they do not agree within this tolerance, each set of fine readings and the initial coarse A+ reading should be inspected for any obviously erratic values. If the mean differences of any set of fine readings varies from the mean of the four sets by more than 8 millimicroseconds, that set should be repeated at the same remote dial setting. If the difference persists, the remote unit operator should be instructed to move to another frequency (a move of one-half or one full graduation in the remote dial setting is sufficient). The master unit operator should then return and take a new set of fine readings. If the inspection of the fine readings reveals no erratic readings, then the initial coarse A+ reading should be verified. In figure 6-12, the mean fine reading (3.44) is compared with A+ (05) in block II and is satisfactory because it is within 4 millimicroseconds.

f. Four sets of fine readings are made using all parts of the CAVITY TUNE dial; i.e., 3, 5, 7, and 9. The use of all parts of the CAVITY TUNE dial will reduce the reflection error until it is so small that it will seldom affect artillery survey accuracies.

6-35. Interpreting the Final Coarse Readings (Block IV)

The final set of coarse readings is taken as a check on the initial coarse readings and is used to resolve the transit time in block V. The final coarse readings are interpreted and the differences are resolved in the same manner as the initial coarse readings. When the differences are resolved, the final coarse differences are compared with the initial coarse differences. If the differences between the patterns of the two sets exceed that shown below, a third set of coarse readings is taken and the pattern differences are resolved and compared with the first two sets. Of the two sets that compare most favorably, the last set taken is accepted for the final coarse readings and is used to resolve a transit time.

Pattern Difference	*Maximum Difference*
A+, A—	4
A+, B	8
A+, C	8
A+, D	2

6-36. Resolving the Transit Time from Pattern Differences (Block V)

a. In the spaces provided in block V (fig 6-12), enter the *final coarse reading differences* from block IV, the mean fine reading (to the nearest hundredth) from block III, and the first figure (transit time) from block X (approximate distance in miles).

BLOCK V - TRANSIT TIME (III, IV, & V)

Obtained from approximate distance in miles (block V)		0	0	0	0	0	0	0	0	From block V, enter 0 on line for resolved transit time (Approx. dis. miles from map scale = 2.3 miles)
Final	A+B Diff		2	8	0	0	0	0	0	To compare with A+B Diff consider: 3380344, (2380344), 1380344 = (value closest to 28000; enter 2 on line for resolved transit time)
Coarse	A+C Diff			4	1	0	0	0	0	To compare with A+C Diff consider: 580344, 480344, (380344) = (value closest to 4100; enter 3 on line for resolved transit time)
Readings (block IV)	A+D Diff				8	2	0	0	0	To compare with A+D Diff consider: 90344, (80344), 70344 = (value closest to 820; enter 8 on line for resolved transit time)
Mean fine reading (block III)						0	3	4	4	Use this value to compare with A+D Diff. Enter the mean fine reading from block III. This value will not change.
Unresolved transit time (block III)		0	2	4	8	0	3	4	4	Unresolved transit time
Resolved transit time (block III)		0	2	3	8	0	3	4	4	Resolved transit time

Figure 6–15. Resolving a transit time.

b. On the line for unresolved transit time, bring down the first digit appearing on each line in block V and the complete value of the mean fine reading and enter them as the unresolved transit time.

c. Determine the resolved transit time by successive comparison and enter the value on the line for resolved transit time (fig 6–12). The method of comparison used to resolve a corrected transit time is illustrated in figure 6–15. The resolved transit time respresents the travel time in millimicroseconds of the electromagnetic wave transmitted from the master unit to the remote unit and return.

6–37. Computing Slope Distance in Meters (Block VII)

a. The resolved transit time in millimicroseconds is a time measurement which must be corrected for the refraction of atmosphere and converted to a one-way slope distance in meters. The log of the resolved transit time is entered in line 1 of block VII.

b. A mean refraction index is used in artillery survey for the refraction correction. This index eliminates the requirement for meteorological observations during a measurement and simplifies computations. This index has been applied to the velocity of a radio wave per millimicrosecond to provide a constant. The logarithm of one-half the constant is added to the log of the resolved transit time to produce the logarithm of a one-way slope distance in meters. This logarithm appears on line 2, block VII (fig 6–12), and is added to the logarithm on line 1; the resulting sum is the logarithm of the slope distance in meters (line 3, block VIII).

c. The use of a mean refractive index will provide an accuracy greater than 1:10,000 at air temperatures of —40° F to +120° F at elevations of —1,000 to +10,000 feet, and under all conditions of humidity.

6–38. Determining the Vertical Angle (Block VIII)

a. In block VII, the logarithm of the slope distance was determined. This distance must be converted to an equivalent horizontal distance to be used in artillery survey. The horizontal distance can be computed by using the slope distance and the vertical angle or the slope distance and the difference in height.

b. When the vertical angle is measured, it is entered on line 5 in block VIII (fig 6–12). The vertical angle should be measured reciprocally or corrected for curvature, when measuring over a long distance (greater than 1000 meters). The vertical angle may be expressed in either degrees, minutes, and seconds or in mils, depending on the type of theodolite used to make measurement.

c. If the vertical angle is not measured, then it must be computed by using the slope distance and the difference in height. The difference in height is obtained from line 3, block I, at the top of the form. The vertical angle is computed in block VIII.

d. The heights of the master station and the remote station are entered on lines 1 and 2, respectively, in block I. The heights are obtained from known data or determined with the altimeter (chap 11).

6–39. Reducing Slope Distance to Sea Level Distance (Block IX)

a. The slope distance is reduced to sea level distance by computations, using the slope distance, vertical angle, and sea level coefficient. The computations are made by following the instruction in block IX (fig 6–12).

b. The instructions for the use of the sea level coefficient are on the back of the form in block XI (fig 6–13).

c. The computations on the field record and computations form end with sea level distance in block IX. To carry the computations further would be a duplication of effort, since most Department of the Army artillery survey forms provide for the application of the log scale factor to convert sea level or ground distance to universal transverse mercator grid distance.

6–40. Personnel Requirements

One man can operate either the master or the remote unit. However, in order to take advantage of the accuracy and speed of a Tellurometer survey, two men—an instrument operator and a recorder —are required for each unit. As in all field artillery survey operations, two independent computations must be made.

6–41. Tellurometer Traverse

a. The primary use of the Tellurometer in field artillery survey is to measure distance for traverse and trilateration. However, it can be used to measure any required distance between 150 meters and approximately 64,000 meters (40 miles). The main advantages of determining distance with a Tellurometer rather than with a tape are:

(1) Greater accuracy.

(2) Greater ease in measuring over rough terrain.

(3) Less time required to measure long distances.

b. Short distances (greater than 150 meters but less than 1,000 meters) can usually be determined in less time with a tape than with the Tellurometer. Because of the necessity of distributing survey control throughout an area of operations, the average distance measured in a Tellurometer traverse is from 1 to 5 miles.

c. A set of Tellurometer equipment consists of one master unit and two remote units. In Tellurometer traverse, the master station is the midstation and the remote units are located at the forward and rear stations. The master unit occupies alternate stations and measures the distance to the rear station and the forward station each time it is set up. Horizontal and vertical angles are measured at each Tellurometer station. When measuring is complete at the first three stations, the master station and the rear remote station are moved to the next successive stations (fourth and fifth stations, respectively). The former forward remote station remains in position and becomes the rear remote station. The procedure is continued with the master station being positioned between two remote stations until measurements are completed.

d. The theodolite is the angle-measuring instrument used with the Tellurometer. Generally, the Tellurometer is used in artillery fourth-order survey, using forth-order specifications. If the Tellurometer is used for artillery fifth-order survey, distances are measured in the same manner as for artillery fourth-order survey, and angles are measured to fifth-order specifications. In either case, one theodolite is provided with each master

and remote unit. An altimeter is also provided with each master and remote unit for the determination of height when a vertical angle cannot be measured.

e. The tripod should be set up over the station and used for both the Tellurometer and the theodolite. The instrument operator and the recorder perform both distance measurements and angle measurements.

6–42. Trilateration by Tellurometer

a. Trilateration is another method of survey for which the Tellurometer may be used. Trilateration is the measurement of the length of the sides of a triangle and computing the three interior angles.

b. Trilateration may be performed when Tellurometer traverse is eliminated as a means of extending survey control because poor visibility prohibits the use of an angle-measuring instrument. When trilaterating under these conditions, height is established by altimetry and azimuth is determined with the azimuth gyro.

c. Generally, trilateration will not be used when a Tellurometer traverse is possible, because in most tactical situations and conditions of terrain, a Tellurometer traverse is faster, more accurate, less complicated, and also requires fewer computations and less reconnaissance.

Note. See appendix B for trilateration specifications using Tellurometers.

6–43. Care and Maintence of the Tellurometer

a. The number of artillery surveyors with a sufficient knowledge of electronics to perform all adjustments and repairs of the Tellurometer is very limited. For this reason, the operator's maintenance should be confined to a level suitable for personnel accustomed to conventional survey equipment.

b. The Tellurometer is a relatively delicate instrument. Unlike conventional survey equipment, the Tellurometer is susceptible to many effects besides those caused by rough handling.

c. TM 5–6675–296–12 is the operator's manual for the Tellurometer. This manual clearly defines the extent of care and the maintenance category. The operator should consult this manual regularly in performing his maintenance. *Maintenance experimentation by operating personnel is prohibited.*

Note. There are two models of the military Tellurometer now in existence. The Tellurometer MRA 1 has been replaced by the Fairchild MC 8 (DME); however, the MRA 1 is presently in use in the field by some troop units. The newest model, the Tellurometer MRA 301, is under procurement and will be an item of issue to using units in the future. The appearance, operation, and distance computations with the MRA 301 are similar to those of the DME. The two instruments can be used interchangeably for measuring distances.

Section III. SURVEYING INSTRUMENT, DISTANCE MEASURING ELECTRONIC

6–44. General

The DME (distance-measuring equipment), an electronic distance-measuring device (fig 6–16), replaces the Tellurometer (MRA–1) as an item of issue in tables of organization and equipment of most field artillery units required to perform fourth-order survey. The DME system consists of three units which may serve either as a measurer or a responder simply by turning a selector switch. In the DME system, units are designated as measurer or responder, depending on the mode selected, and correspond respectively to the master and remote functions in the Tellurometer system. Measurements with the DME cannot be made through land masses or large obstructions, such as houses, which are directly in the line of sight and near either of the units. However, measurements can be made when small, distant objects, such as trees, brush, chimneys, or small buildings, lay on the line of sight. Visibility is not required for measurements with the DME as it is for an optical instrument. The minimum range capability of the DME is 200 meters; the maximum range capability, 50 kilometers (approximately 35 miles). Approximately 30 minutes are required to measure and compute any distance within the instrument's capability. A distance can be measured during daylight or darkness and through fog, dust, or rain.

6–45. Description of Components

a. The dimensions of the DME are 15 x 14 x 10 inches; it weights 34.5 pounds. The unit has a built-in aerial and communication system for use during the setup and measurement periods. A luggage-type handle on the instrument permits the

Figure 6–16. DME station with operating equipment.

instrument to be carried when it is removed from its carrying case.

b. The instrument is contained in a metalized fiberglass case.

c. The tripod issued with the DME is similar to, and interchangeable with, the tripod used with the Tellurometer, the 0.2 mil and 0.002 mil theodolites.

d. The units may be operated from either a 12- or a 24-volt, DC power source or a 110-volt, 60-cycle AC source with a converter or a self-contained 12-volt nickel cadmium battery.

e. Additional accessories include—

(1) A set of Allen wrenches.
(2) A screwdriver-type wrench.
(3) A screwdriver.
(4) A 24-volt cable (25 feet).
(5) A 12-volt cable (6 feet).
(6) A connector for the internal battery.
(7) A headset.
(8) A nickel cadmium battery.
(9) An instructional manual.

6–46. Selection of Stations

Electronic line of sight is required between the two units of the DME system. The principles to be considered in selecting the stations for the DME are the same as those for the Tellurometer (para 6–26).

6–47. Operator Training

a. An instrument operator qualified to operate conventional surveying instruments, especially the Tellurometer, can acquire in approximately 60 minutes an adequate knowledge of the DME to perform and supervise all the activities required to complete a field observation and to perform the necessary computations for the determination of a distance.

b. Continued operation of the DME will provide the operator with sufficient knowledge to perform a limited amount of maintenance.

6–48. Instrument Controls

The physical location of the DME controls are shown in figure 6–17. The functions of the individual controls are as follows:

a. ON-OFF-STANDBY Switch. The ON-OFF-STANDBY switch is used to apply power to the equipment. This switch is located in the lower left section of the control panel. When the switch is—

(1) In the OFF position (horizontal), none of the circuits are energized.

(2) In the STANDBY position (down), the klystron filament and the crystal oscillator oven are energized. This permits the instrument to warm to operating temperature.

***Caution:* Do not switch from OFF STANDBY to ON until the warning cycle has been completed.**

(3) In the ON position (up) all circuits required for distance measurement are energized.

b. VOLUME Control. The VOLUME control is located next to the ON-OFF-STANDBY switch. This control adjusts the gain of the circuits driving the headset earphones. The control may be turned down to zero.

c. ILLUMINATION Control. The ILLUMINATION control is located approximately in the

center of the control panel. This control adjusts the brightness of the seven lamps on the control panel. The lamps are turned off in the fully counter-clockwise position of the control.

d. MEASURE-TALK Switch. The MEASURE-TALK switch is located just above the ILLUMINATION control. When the switch is in the TALK position, voice communication between the units is possible. When the switch is in the MEASURE position, the circuits that determine the distance between units are connected.

e. MONITOR Meter. The MONITOR meter is located in the upper left corner of the control panel. After the minimum meter reading is determined, the responder instructs the measurer to rotate his instrument in azimuth to also determine a minimum meter reading. In the TALK mode, the meter deflection is proportional to voltages in the circuits being monitored.

f. MONITOR Switch. The MONITOR switch is a seven-position switch located just below the MONITOR meter. The switch positions and the circuits monitored are listed below.

Switch position	*Circuit Monitored*
OVEN	Oven heater current
RF	Mixer crystal current
AFC	Output of AFC amplifier
SIG	Sample of AGC voltage
−12	−12 volt supply
+12	+12 volt supply
DC IN	DC input voltage

g. FREQUENCY Control. The FREQUENCY control is in the center of the top row of controls on the control panel. This control is used to tune the responder to the frequency of the measurer.

h. HIGH-LOW Switch. The HIGH-LOW switch is located below and to the right of the FREQUENCY control. It is controlled only by the responder unit. In the HIGH position, frequency tuning is attained when the responder frequency is about two units *higher* than that of the measurer. In the LOW position, frequency tuning is attained when the responder frequency is about two units *lower* than that of the measurer.

i. CHANNEL Switch. The CHANNEL switch is located in the upper right-hand corner of the control panel. This switch is used to select the measurer or responder mode of operation. Those positions marked "M" allow the unit to operate in the measure mode, and those positions marked "R" allow the unit to operate in the responder mode. There are six channels in either mode which are used to resolve each digit of the distance being measured.

j. COUNTER Dial. The COUNTER dial is located near the center of the control panel. The COUNTER dial has a range of 000 to 999. The COUNTER dial is geared to the COUNTER control.

k. COUNTER Control. The COUNTER control is located to the right of the COUNTER dial. This control is geared to both the COUNTER dial and the resolver. During measurements, the COUNTER knob is rotated clockwise until the MONITOR meter needle also moves in a clockwise direction and is nulled (rests at zero). The value which appears on the COUNTER dial is then extracted as observed field data.

6–49. Setting up Procedure

The procedures for setting up the DME are as follows:

a. Before going into the field, determine—

(1) The time at which contact will be established.

(2) Which operator will initially be the measurer.

(3) The approximate locations of the stations and the direction toward each other.

(4) The frequencies to be used.

b. Place the tripod over the stations with one tripod leg pointing to the station at the other end of the line to be measured. This is important because the front leg will be used later to elevate the instrument through a vertical angle during the orienting procedure. A plumb bob should be used to center the tripod approximately, but exact plumbing is unnecessary at this time, since the instrument will be moved slightly during orientation.

c. Remove the instrument from its case and place it on the tripod head. Thread the tripod screw into the base of the instrument. Do not tighten the screw completely. Point the dipole in the approximate direction of the opposite unit. In windy weather, the DME should be tied down so that it will not be blown over and damaged.

d. Remove the control panel cover and the antenna cover.

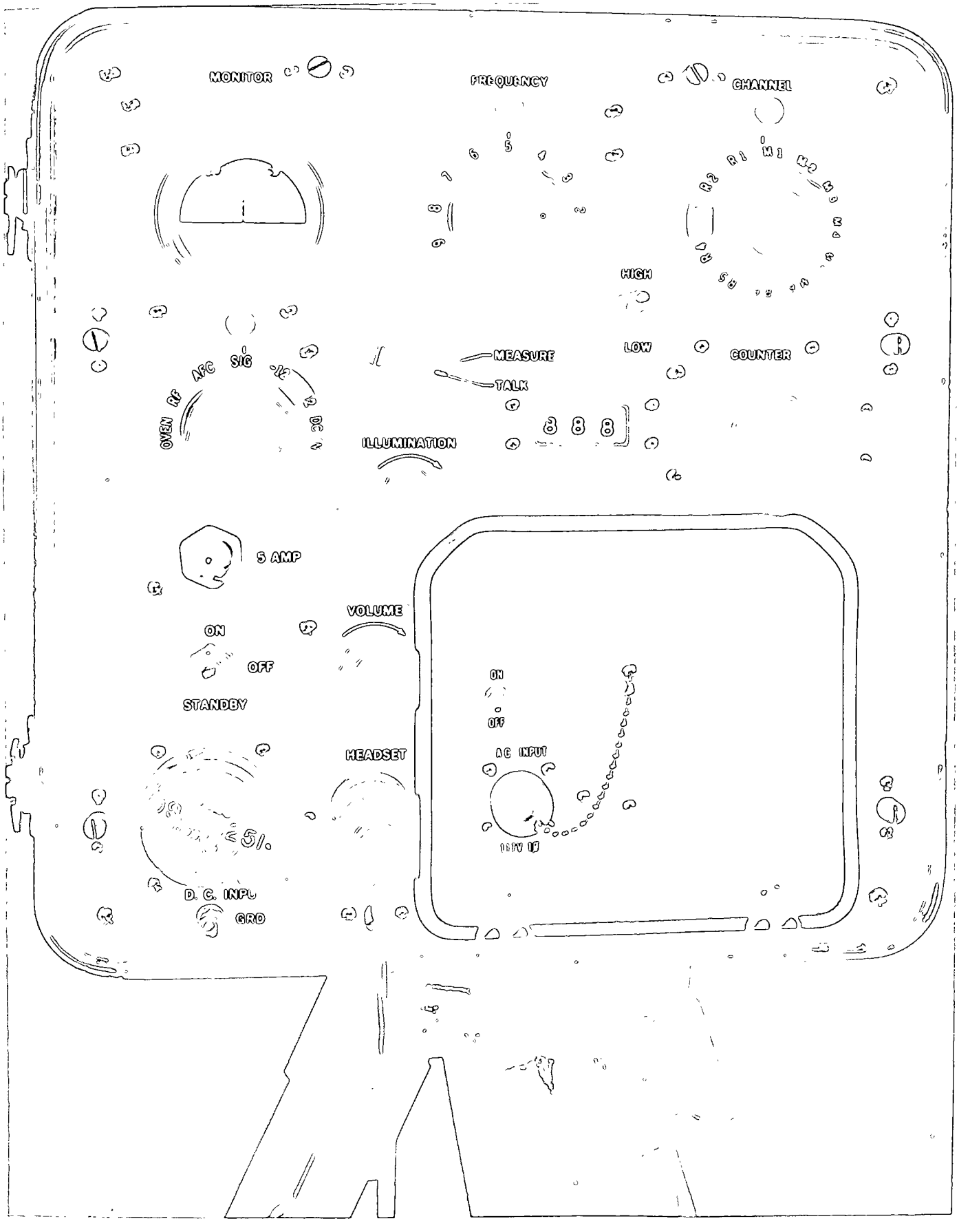


Figure 6–17. Control panel of the DME.

e. See the controls and switches in the following position:

Controls	*Measurer*	*Responder*
ON-OFF-STANDBY switch	OFF	OFF
MONITOR switch	OVEN	OVEN
MEASURE-TALK switch	TALK	TALK
HIGH-LOW switch	HIGH	HIGH
CHANNEL switch	M6	R6
FREQUENCY control	1	3
VOLUME control	Clockwise	Clockwise
ILLUMINATION control	Clockwise, as required	Clockwise, as required

f. Select the power cable or connector suitable for the power source being used:

Power Source	*Cable or Connector*
12V DC internal battery	Connector
12V DC external battery	6-foot cable
24V DC external battery	25-foot cable

Note. The connector is an accessory device which routes current from the internal battery to the circuitry of the instrument.

g. Connect the power cable or connector to the EXTERNAL DC INPUT receptacle on the control panel. If an external source is to be used, connect the power cable clips to the power source. *Connect the clip with the black insulator to the negative terminal of the power source and the clip with the red insulator to the positive terminal of the power source.*

Note. A chassis ground terminal is provided on the control panel. Under normal usage, no connection is required.

h. Connect the headset plug to the HEADSET receptacle on the control panel.

i. Set the ON-OFF-STANDBY switch to STANDBY. The unit must remain in the STANDBY mode at least 2 minutes in moderate weather, and up to 15 minutes in extreme cold weather, to allow the crystal oven heaters in the oven boost cycle to warm to the proper operating temperatures. When a 12-volt battery is being used, the MONITOR needle initially rests at the extreme left, beyond the 10 graduation; completion of the boost cycle is indicated when the needle drops abruptly to 8. When a 24-volt battery is being used, the MONITOR needle initially rests at the 8 graduation; completion of the boost cycle is indicated when the needle drops abruptly to 4.

Note. Only the monitor functions OVEN and DC IN can be checked while the unit is in the STANDBY mode.

j. After the oven boost cycle has been completed, set the ON-OFF-STANDBY swtich to ON. Rotate the MONITOR swtich through the FR, —12, +12, and DC IN positions and observe the MONITOR meter readings. The meter readings should be as follows:

Position	*Required Meter Reading*
RF	Between +3 and +10
−12	+10
+12	+10
DC IN	+10

k. Adjust the VOLUME control until background noise is audible in the headset.

6–50. Tuning Procedures

The instrument tuning procedures follow the setting up procedures and must be completed prior to making a measurement. Contact between the two stations is achieved when the antennas of both units are directed toward each other and the panel controls are set properly. Contact can be established at more than one FREQUENCY control setting. False indications are more probable at shorter distances. The remote operator should search for the strongest SIG indication (lowest reading on the MONITOR meter) in order to eliminate all false indications. After the instrument has been set up (para 6–49)—

a. Set the MONITOR switch to the SIG position on both units.

b. (Responder only) At the predetermined time, rotate the FREQUENCY control approximately one division each way while observing the MONITOR meter and listening to the headset. Contact with the other unit will be indicated by a simultaneous decrease in the meter readings and a decrease in the background noise in the headset. At this time, voice communication is possible.

c. (Responder only) Set the MONITOR switch to the AFC position. Null the meter at zero, midscale, by rotating the FREQUENCY control slowly clockwise if the meter reads to the left or counterclockwise if the meter reads to the right of zero.

Note. If contact is lost, repeat the steps in *a* through *c* above.

d. (Responder only) Set the MONITOR switch to SIG and slowly rotate the instrument in azimuth for the strongest signal (minimum meter reading). When the minimum reading has been obtained, instruct the measurer to slowly rotate his instrument in azimuth for the strongest signal strength.

e. (Responder only) Slowly rotate the instrument in elevation by adjusting the forward tripod leg for a minimum reading (strongest signal) on the MONITOR meter. Instruct the measurer to slowly move his instrument in elevation until he receives the strongest signal.

f. At this time, the plumb bob on the tripod may be off the station point. Loosen the tripod screw and reposition the plumb bob by slowly moving the instrument; then retighten the screw.

g. All operations necessary for contact between stations are now accomplished. If contact is lost, responder is responsible for reestablishing contact with the measurer. To reestablish contact, the responder readjusts the FREQUENCY control and repeats the steps in *b* and *c* above.

h. If contact is *not* established after the procedure in *a* through *e* above has been executed, follow the steps in (1) through (3) below.

(1) (Responder only) Rotate the instrument in azimuth approximately 100 mils and repeat the steps in *b* through *f* above.

(2) (Responder only) Repeat the step in (1) above until contact is established or until the instrument has been moved plus and minus 800 mils (45°) in azimuth from the initial direction. Return the instrument to the original azimuth.

(3) If contact has not been established within 20 minutes after the predetermined contact time, the measurer should follow the steps in (1) and (2) above. While the measurer is changing the direction of the antenna, the responder should continue searching in FREQUENCY.

6-51. Measuring Procedure

A DME measurement consists of two complete sets of readings in both the forward and reverse directions. In the forward direction, frequencies 1 and 5, with the responder's HIGH-LO switch in the HIGH position, are used for the two sets. In the reverse direction, frequencies 5 and 9, with the responder's HIGH-LOW switch in the LOW position, are used. If communication is lost at any time during measurements, the responder, not the measurer, is responsible for reestablishing contact.

a. (Responder) After establishing communication, inform the measurer by announcing MEASURE.

b. (Both operators) Set the MEASURE-TALK switch to the MEASURE position. Listen for a tone in the headset. This is the measuring tone, and it should always be audible when the instrument is operating properly.

c. (Measurer) Rotate the COUNTER knob clockwise until the MONITOR meter needle also moves clockwise. Stop the needle at zero. This is called nulling the meter. If the needle moves counterclockwise, the reading obtained on the COUNTER dial will be 500 units in error.

d. (Measurer) Read the COUNTER dial and announce its value to the recorder.

e. (Measurer) Switch the CHANNEL swtich to M5. This will eliminate the measure tone and cause the responder's MONITOR meter needle to deflect.

f. (Responder) Upon hearing the loss of tone, switch the CHANNEL switch to R5.

g. (Measurer) Repeat *c*, *d*, and *e* above.

h. (Measurer and responder) Repeat *c* through *f* above for the remaining channels, M4 and R4 through M1 and R1.

i. (Measurer) After recording the M1 reading, switch the MEASURE-TALK switch to TALK and announce FREQUENCY 5. This indicates that the measurer will change his frequency to 5.

j. (Measurer) Set the FREQUENCY control to 5 and the CHANNEL switch to M6.

k. (Responder) Set the CHANNEL switch to R6 and repeat the tuning procedure in *b* and *c* above.

l. (Measurer and responder) Repeat *a* through *i* above to obtain another set of readings.

Note. The modes of operation will now be reversed; that is, the measurer will become the responder and the responder will become the measurer.

m. (Measurer) Set the CHANNEL switch to R6 and the HIGH-LOW switch to LOW.

n. (Responder) Set the CHANNEL switch to M6 and the FREQUENCY control to 5.

o. (New measurer and responder) Repeat *a* through *i* above to obtain the first set of readings in the opposite direction.

p. (New measurer and responder) Repeat *a* through *i* above to obtain the second set of readings in the opposite direction, but use frequency 9.

Note. This completes two sets in each direction.

6-52. Computing a DME Distance Measurement

DME distance measurements normally are computed at the station acting as the measurer. The reverse distance is obtained from the opposite station after measurement, and both stations compute the final sea level distance before party per-

sonnel depart for subsequent survey operations. This permits the verification of the distance determined by map scaling and the resolution of ambiguous readings if they occur. Figure 6–18 illustrates the recording of readings on DA Form 2972 (Field Record and Computations—DME) and is used as a reference for the discussions on computations in paragraphs 6–53 and 6–57.

6–53. DME Form (Block I)

Block I is used to record all station information and elevations determined by altimetry. In space A, the instrument number, operator's name, and height of the station in meters (if altimetry is used) refer to the measurer station. The same data in space B refers to the responder station. On the right side of block I, spaces are provided for listing weather conditions and the name of the recorder at the measuring station.

6–54. Initial Readings (Block II)

Block II is provided for recording counter readings observed in each of the channels M6 through M1, at frequency 1. In addition, space is provided for recording the differences M6 minus M1 through M2 minus M1. Since the operator begins observations in channel M6 and selects the next lower channel for each succeeding observation, the readings will be entered from left to right, M6 through M2. The M1 reading is then subtracted from each of the other readings. In some cases the M1 reading will be larger than the other channel reading from which it is to be subtracted. For example, the difference M5 minus M1 equals 093 minus 413 (fig 6–18). If the M1 reading is larger than the channel reading from which it is to be subtracted, 1,000 is added to the smaller number before subtracting in the normal manner (1,093 — 413 = 680).

6–55. Final Readings (Block III)

a. The second set of readings taken in a given direction are recorded in block III and referred to as final readings. The first three lines are used exactly as those in block II. The differences obtained in block II are then transferred to block III. The initial and final differences are added and the sum is divided by 2 to obtain the mean difference.

b. In the remaining row of spaces in block III, the uncorrected resolved distance is entered. This entry requires a process of resolution as shown on the back of DA Form 2972 (fig 6–19) as follows:

(1) Accept the mean M2 minus M1 difference and enter it in the last three spaces of the *resolved distance.* The entry thus far is referred to as a partial resolved distance (fig 6–18).

(2) Add 50 to and subtract 50 from the next channel difference, M3 minus M1. In figure 6–18, this is 487 plus and minus 50 = 537 and 437.

(3) Find a number between 537 and 437 which ends in the first two digits of the partial resolved distance. In figure 6–18 the partial resolved distance is 126 and its first two digits are 12. The only number between 537 and 437 ending in 12 is 512. This is the resolved channel difference.

(4) Prefix the first digit of the resolved channel difference to the partial resolved distance to obtain a new partial resolved distance.

(5) Repeat this process for all succeeding channel differences, using the previously determined new partial resolved distance with each. Resolution of all channel differences provides the uncorrected slope distance.

c. The electronic distance does not coincide with the distance between stations, thus, a small correction must be applied to find the true slope distance. The calibration constant is always minus 0.16 meter.

d. The slope distance measured in the opposite direction at the other end of the line is entered on the next line, and the mean of the forward and reverse distances is entered on the following lines.

6–56. Determining the Vertical Angle Between Stations

a. In block III the slope distance was determined; however, horizontal distance is required for artillery survey. Therefore, the slope distance must be converted to horizontal distance. In order to accomplish the conversion, the vertical angle from station A to station B must be determined. The slope distance is considered to be the hypotenuse of a right triangle. The horizontal distance may be computed by using the slope distance and the vertical angle or the slope distance and the difference in height (block IV).

b. When the vertical angle is measured, it is entered in block I and on line 5 in block IV. The vertical angle should be measured reciprocally or corrected for curvature when a distance in excess of 1,000 meters is being measured. The vertical angle may be expressed in mils or degrees, min-

FIELD RECORD AND COMPUTATIONS-DME

BLOCK I-STATION DATA

	Station	Inst. No.	Operator	Height Meters	
A	HARRY	431	SP4 KLINE	452	Weather: CLEAR BRIGHT
B	CHARLIE	446	SP4 BLAIR	439	Recorder: SP4 LAWSON
			Height difference	13	Vertical Angle (if measured)
					← Enter in Block IV

BLOCK II-INITIAL READINGS

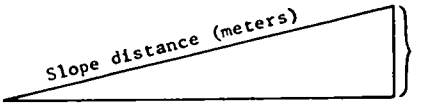
Frequency	M6	M5	M4	M3	M2
	754	093	486	899	537
Minus M_1	413	413	413	413	413
Initial Difference	341	680	073	486	124

BLOCK III - FINAL READINGS

Frequency	M6	M5	M4	M3	M2
	764	095	494	903	543
Minus M_1	415	415	415	415	415
Difference	349	680	079	488	128
Initial Difference	341	680	073	486	124
Sum of Differences	690	1360	152	974	252
Mean of Difference	345	680	076	487	126

Reaolved diatance (See note)	3	7	0	5	1	2	6
Calibration conatant					−	1	6
Slope diatance A to B	3	7	0	5	1	1	0
Reverae alope diatance B to A	3	7	0	5	1	1	2
Mean slope distance (meters)	3	7	0	5	1	1	1

BLOCK IV-VERTICAL ANGLE



1	Difference height meters	13.0
2	Log (1)	1 113 9434
3	Log mean slope distance (III)	4 568 8012
4	(2)-(3) Log sin vertical angle	6 545 1422
5	Vertical angle [log sin (4)]	0 000 36

NOTE: Directions for resolving the diatance are given on reverse side of form.

BLOCK V - SEA LEVEL DISTANCE METERS

1	Log mean slope distance (IV-3)	4 568 8012
2	Log cos vertical angle (I)	0 000 0000
3	(1)+(2) = Log horizontal distance	4 568 8012
4	Log sea level coefficient (VI)	9 999 9727
5	(3)+(4) = log sea level distance	4 568 7739
6	Sea level distance - meters (If necessary)	37,048.77

BLOCK VI - SEA LEVEL COEFFICIENT

Use height of station or mean height between stations to nearest 100 meters

Height meters	Log sea level coefficient	Height meters	Log sea level coefficient	Height meters	Log sea level coefficient	Height meters	Log sea level coefficient	Height meters	Log sea level coefficient
-100	0.0000068	500	9.9999659	1300	9.9999112	2100	9.9998566	2900	9.9998020
- 50	0.0000034	600	9.9999590	1400	9.9999044	2200	9.9998498	3000	9.9997951
00	0.0000000	700	9.9999522	1500	9.9998976	2300	9.9998429	3100	9.9997883
50	9.9999966	800	9.9999453	1600	9.9998908	2400	9.9998361	3200	9.9997815
100	9.9999931	900	9.9999386	1700	9.9998839	2500	9.9998292	3300	9.9997747
200	9.9999863	1000	9.9999317	1800	9.9998770	2600	9.9998225	3400	9.9997678
300	9.9999795	1100	9.9999249	1900	9.9998703	2700	9.9998156	3500	9.9997609
400	9.9999727	1200	9.9999181	2000	9.9998634	2800	9.9998088	3600	9.9997542

Computer SP5 CLIFTON	Checker SP5 BURKE	Sheet 1 of 2 sheets	
Notebook Reference	Area APACHE GATE		Date 21 NOV 68

DA FORM 2972
MAY 65

Figure 6-18. DA Form 2972, Field Record and Computations—DME.

To transpose mean differences to a resolved distance in Block III, follow the directions below:

DIRECTIONS	EXAMPLE
	CHANNEL DIFFERENCES
	M6-M1 / M5-M1 / M4-M1 / M3-M1 / M2-M1
	345 / 680 / 076 / 487 / 126
1. Accept the M2-M1 difference as a partial resolved distance.	1. The partial resolved distance is 1.26
2. Add 50 to and subtract 50 from the next difference (M3-M1).	2. 487 ± 50 = 437 and 537
3. Find the number which ends in the first two digits of the partial resolved distance and which lays between the two numbers determined in step 2.	3. The only number ending in 12, which lies between 437 and 537 is 512.
4. Prefix the first digit of the number determined in step 3 to the partial resolved distance previously determined to obtain a new partial resolved distance.	4. Since 5 is the first digit of the number determined in step 3, it is prefixed to 126. 51.26
5. Repeat steps 2 through 4 until all channels have been resolved.	Resolving M4-M1 The only number ending in 51, which lies between 026 and 126 is 051 051.26 Resolving M5-M1 The only number ending in 05, which lies between 630 and 730 is 705. 7051.26 Resolving M6-M1 The only number ending in 70, which lies between 295 and 395 is 370. 37,051.26 The complete resolved distance is 37,051.26

Figure 6-19. Back of DA Form 2972.

utes, and seconds, depending on the type of theodolite used to make the measurement.

c. If the vertical angle is not measured, it must be computed by using the slope distance and the difference in height. The difference in height is obtained from block I. The heights of stations A and B are entered in block I. These heights are obtained from known data or determined with the altimeter (chap 12).

6-57. Reducing the Distance Measured From Slope Distance to Horizontal Distance to Sea Level Distance (Block V)

a. The slope distance is reduced to sea level distance by computations, using the mean slope distance, vertical angle, and sea level coefficient. The computations are made by following the step-by-step instructions in block V.

b. The instructions for the use of the sea level coefficient are given in block VI (when the heights of both stations are known, use mean height (to nearest 100 meters) between stations).

c. The computations on the field record and computations form end with sea level distance. To carry the computations further would be a duplication of effort, since most Department of the Army artillery survey forms provide for the application of the log scale factor to convert to universal transverse mercator grid distance.

6–58. Personnel Requirements

The composition of the survey party and the duties of the personnel for the DME traverse are the same as those for the Tellurometer traverse (para 6–40).

6–59. DME Traverse

The principles of conducting a traverse with the DME are the same as those for conducting a traverse with the Tellurometer (para 6–41), except that each DME may function as both measurer and responder.

6–60. Trilateration

The DME is used in trilateration in the same manner as the Tellurometer (para 6–42).

Note. See appendix B for trilateration using DMEs.

6–61. Care and Maintenance of the DME

The operator's manual for the DME TM 5–6675–227–15, clearly defined the extent of care and the maintenance responsibilities from the operator to the highest maintenance category. The operator should consult this manual regularly while performing his maintenance. *Maintenance experimentation by operating personnel is prohibited.*

6–62. Troubleshooting

Operators are not permitted to make any repairs on the DME, but they must be able to recognize symptoms of malfunction or faulty operation. A list of symptoms, possible causes, and corrective actions that do not constitute repairs is given below.

Symptom	*Possible Cause*	*Corrective Action*
No DC IN meter reading	Power cable is not firmly connected. Cable clamps are not making contact at battery terminals because of surface corrosion or foreign matter.	Check cable to see that it is secure. Rotate clamps slightly so that terminal is scratched slightly for better contact.
	Dead battery.	Charge battery.
	Connector is not attached (when internal battery is used).	Attach connector.
	Connector is not securely attached.	Check to see that connector is screwed completely on and is not crooked.
	Cable circuitry is incomplete.	If available, use a cable which has been recently used and is known to be good.
Blows fuse	ON-OFF-STANDBY switch was switched to ON position before completion of oven boost cycle.	Replace fuse and wait for completion of oven cycle before switching from STANDBY to ON.
	Cable connections to battery are reversed (wrong polarity).	Check polarity. Change if reversed and replace fuse.
	24-volt battery is connected to a 12-volt cable.	Connect proper cable.
Any improper meter reading.		Check DC IN and if faulty refer to possible causes for "NO DC IN meter reading."
AFC cannot be nulled.	HIGH-LOW switch is in wrong position.	Set HIGH-LOW switch to proper position.
No output from headset.	Headset unplugged.	Plug in headset.
	Headset plug is not seated properly.	Check headset plug to see that it is not crooked and that it is firmly engaged.
	Defective headset.	Try a headset which has been used recently and is known to be good.
No tone in measure.	TALK-MEASURE switch is in TALK position.	Switch to MEASURE.
	Channel switch is in wrong position.	Set switch to proper channel.
Difficulty in establishing communications.	Antenna cover has not been removed.	Remove antenna cover.
Resolved distance is obviously in error (i.e., the measured distance is much less, or greater, than the known approximate distance).	M2 and M1 readings have been reversed or an M2 has been repeated as M1 when responder failed to switch from M2 to M1.	Contract responder and check M2 and M1 readings.
	Readings were entered in reverse order.	Contract responder and check readings.

CHAPTER 7
ANGLE DETERMINATION

Section I. AIMING CIRCLE M2

7–1. General Description

The M2 aiming circle (fig 7–1) is a small, lightweight instrument that is used in the firing battery and in field artillery survey operations executed to an accuracy of 1:500. Basically, it consists of a 4-power, fixed-focus telescope mounted on a body that permits unlimited horizontal and limited vertical rotation of the telescope. Horizontal and vertical angle measurements are recorded on graduated scales and micrometers. The aiming circle has two horizontal rotating motions. The upper (recording) motion changes the readings of the azimuth scales of the instrument; the lower (nonrecording) motion does not. The aiming circle is equipped with leveling screws, level vials, and a magnetic compass. The instrument is mounted on a base plate that serves as the base of the carrying case and is also used in mounting the instrument on a tripod.

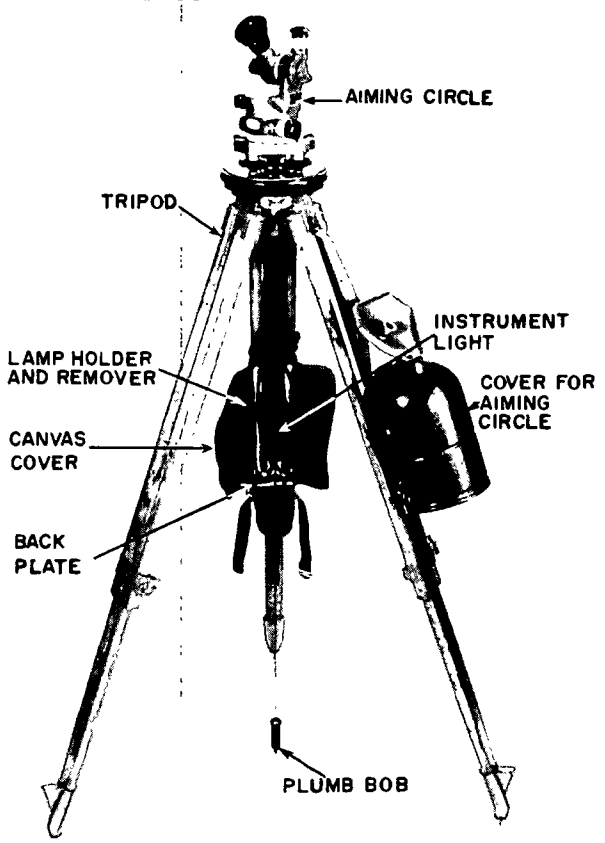


Figure 7–1. Aiming circle with accessory equipment.

The aiming circle M2 consists of the aiming circle body and the accessory equipment. The aiming circle without accessory equipment (para 7–2) weighs 8 pounds 2 ounces and with accessory equipment weighs 22 pounds.

7–2. Aiming Circle Body

The aiming circle body is made up of four principal parts—the telescope body assembly, the body assembly, the worm housing, and the base plate assembly (fig 7–2).

a. Telescope Body Assembly. The telescope body assembly consists of the optical system, the vertical level vial, the reflector, and a filter for solar observations.

(1) *Optical system.* A 4-power, fixed-focus telescope forms the optical system of the aiming circle. The telescope reticle is formed by a glass etched with a horizontal and a vertical crossline intersecting at the center of the telescope. These crosslines are graduated at 5-mil intervals from the center. The graduation range from 0 to 85 mils and are numbered every 10 mils (fig 7–3). These graduations are used to measure relatively small horizontal and vertical deviations from a reference line (e.g., in a high-burst registration). The telescope eyepiece (fig 7–4) is inclined upward at an angle of 45° from the axis of the telescope to permit the observer to look down into the telescope while standing erect. Located on top of the inclined portion of the telescope is a machined slot for attaching the instrument night lighting device. The objective end of the telescope is beveled to form a permanent sunshade.

(2) *Telescope level vial.* The telescope level vial is located on the left side of the telescope. This

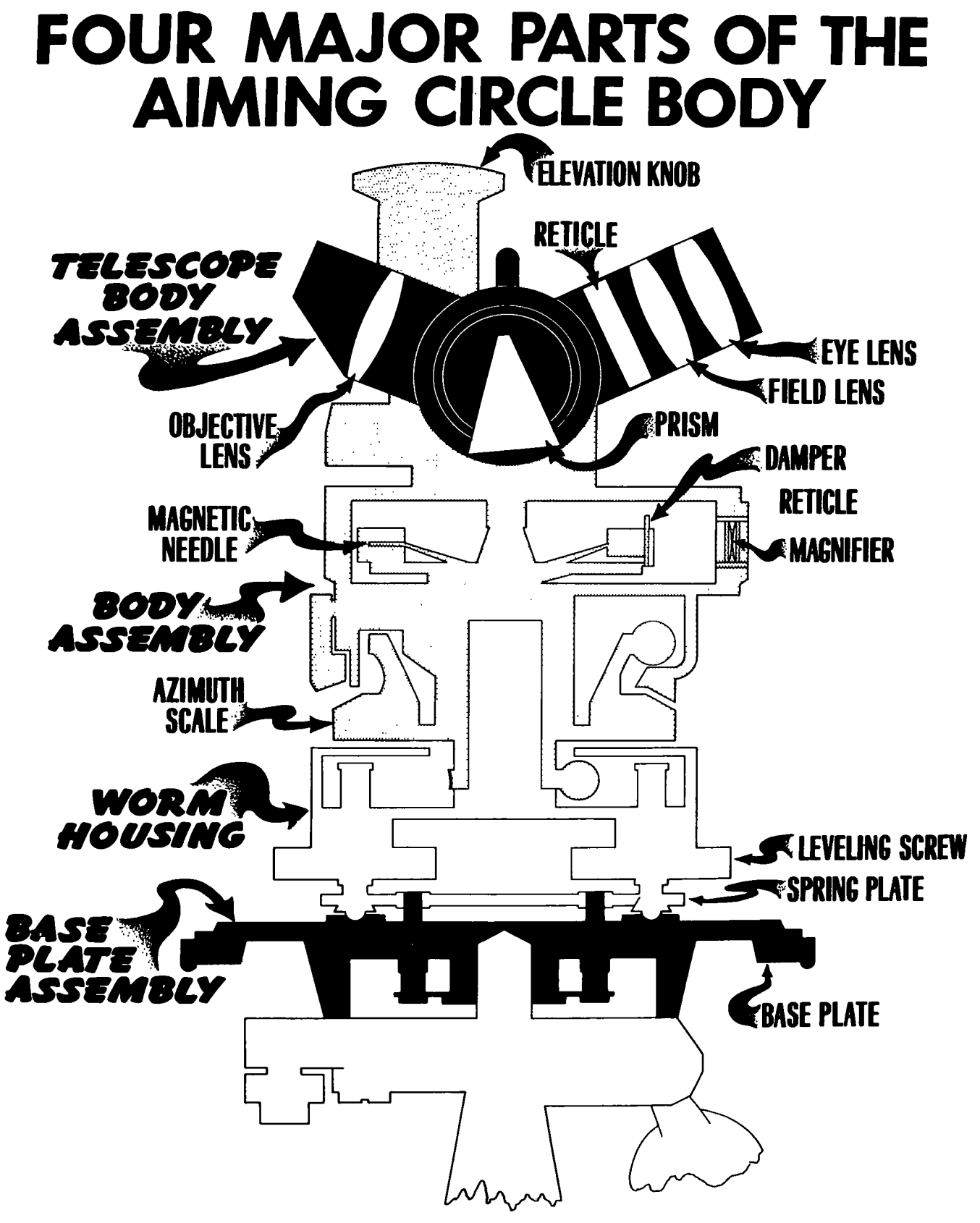


Figure 7–2. Cutaway drawing of aiming circle showing composite parts.

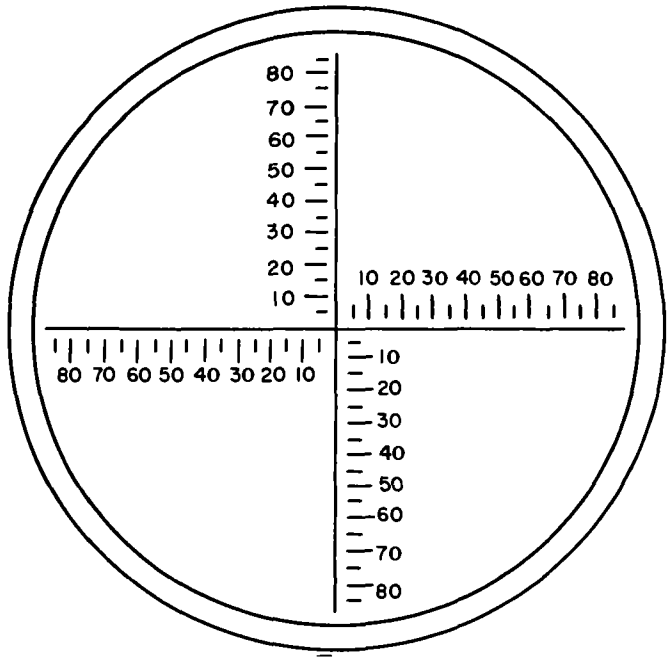


Figure 7–3. Telescope reticle.

level is used to establish the horizontal axis of the telescope in a true horizontal plane. The lugs supporting the telescope level vial are shaped to form an open sight for approximate alinement of the telescope on a station. The telescope level vial is not used in artillery survey.

(3) *Reflector.* The reflector is a plastic signal post mounted on top of the telescope at the vertical axis of the instrument. The reflector is used as an aiming point for other instruments sighting on the aiming circle. At night the reflector can be illuminated externally by use of the instrument light.

(4) *Filter.* A filter is provided for viewing the sun directly when astronomic observations are being made. The filter is slipped onto the eyepiece end of the telescope when the sun is being observed and is attached to the side of the telescope body when not in use.

b. Body Assembly. The body assembly consists of the azimuth and elevation worm mechanisms;

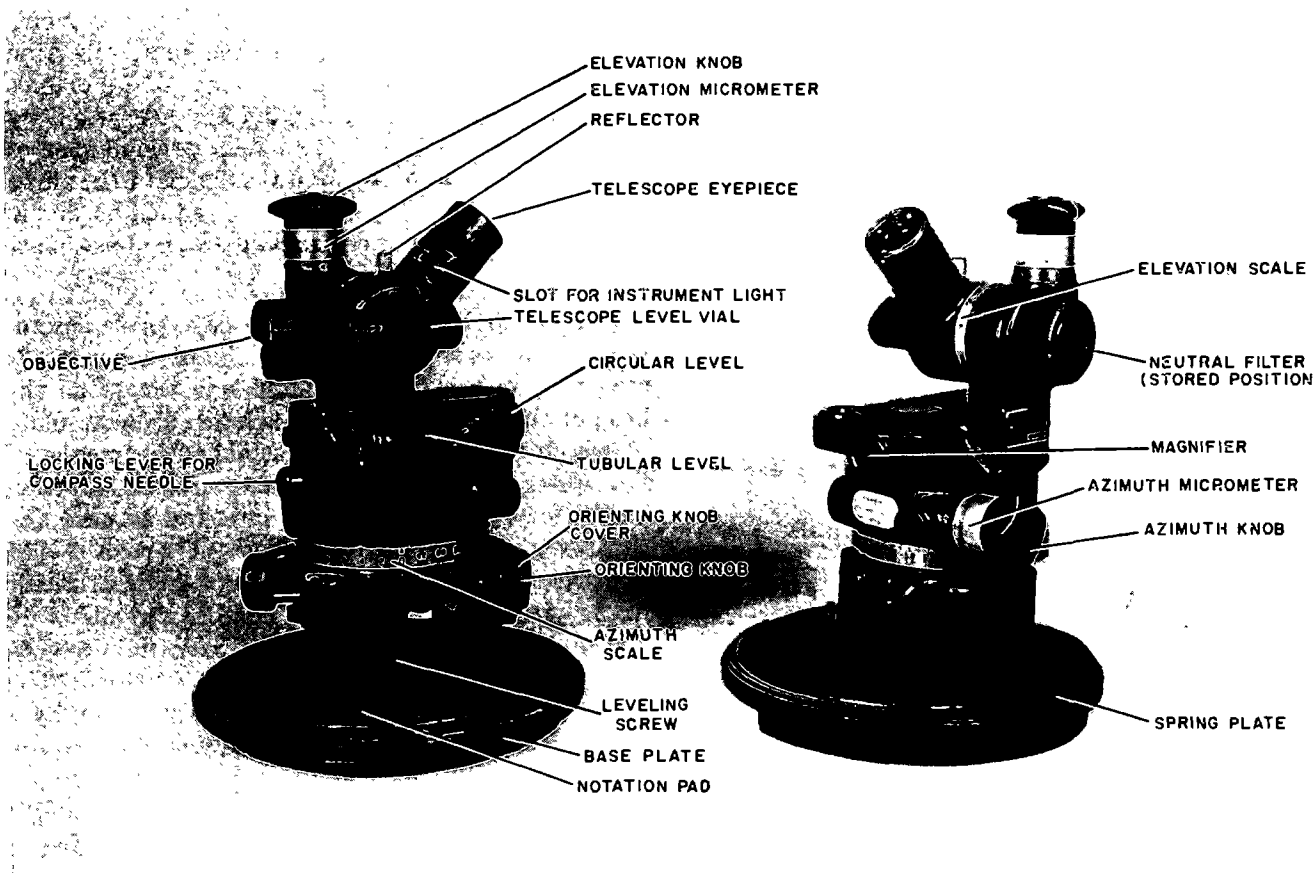


Figure 7–4. Aiming Circle M2.

the magnetic compass, with reticle and needle actuating lever; and two horizontal plate levels.

(1) *Azimuth mechanism.* The azimuth mechanism (upper motion) of the instrument has both a fast and a slow motion. Lateral movement of the azimuth knob permits fast motion. Slow motion is accomplished by rotationg the azimuth knob. Horizontal angles are read in two parts; the hundreds of mils are read from the azimuth scale, and the tens and units of mils are read from azimuth micrometer scale. The azimuth scale is graduated in 100-mil increments from 0 to 6,400 mils and is numbered every 200 mils. The portion of the azimuth scale from 3,200 mils through 6,400 mils has a second scale numbered in red from 0 to 3,200 below the primary scale. The graduations of the primary (upper) scale are used for survey. The second (lower) scale is used for laying the weapons of the firing battery. This lower scale is not used in survey. The azimuth micrometer scale is located on the azimuth knob. It is graduated in 1-mil increments from 0 to 100 mils and is numbered every 10 mils.

(2) *Elevation mechanism.* The elevation mechanism of the aiming circle is similar to the azimuth slow motion mechanism. Stop rings in the mechanism prevent the telescope from striking the body assembly when it is depressed. Vertical angles from minus 400 mils to plus 805 mils can be measured with the aiming circle. Vertical angles are read in two parts; the hundreds of mils are read from the elevation scale, and the tens and units of mils are read from the elevation micrometer scale. The elevation scale is graduated and numbered in 100-mil increments from minus 400 mils to plus 800 mils. The plus and minus symbols are not shown, but the minus numerals are printed in red and the plus numerals are printed in black. The elevation micrometer scale is graduated in 1-mil increments from 0 to 100 mils. The scales are numbered every 10 mils from left to right in black numerals and from right to left in red numerals. The red numerals on the elevation micrometer scale are used in conjunction with the red numerals on the elevation scale. The black numerals on the micrometer scale are used with the black numerals on the elevation scale.

(3) *Magnetic compass.* The magnetic compass is located in the oblong recess in the top of the body assembly. The magnetic needle is limited in movement to approximately 11° of arc and is provided with copper dampers to aid in settling the needle quickly. A small glass magnifier and a reticle with three vertical etched lines are at one end of the recess to aid in alining the south end of the needle. On the opposite end of the recess is a lever which locks or unlocks the magnetic needle. When the lever is in a vertical position, the needle is locked. When the lever is turned either right or left to the horizontal position, the needle is unlocked.

(4) *Horizontal plate levels.* Located on the body assembly at the left side of the magnetic needle recess are two horizontal plate levels; one is a circular level vial that may be used for rough leveling of the instrument, the other is a tubular level vial that is used to accurately level the instrument.

c. Worm Housing. The worm housing is that portion of the aiming circle below the azimuth scale and above the base plate. It contains the worm gear of the orienting (lower or nonrecording) motion, the leveling screws, and the spring plate. The orienting knob controlling the nonrecording motion of the aiming circle is similar in operation to the azimuth (recording) motion of the aiming circle in that lateral movement of one orienting knob permits fast movement in the orienting motion of the aiming circle. The two orienting knobs should be turned in the same direction simultaneously for slow movement of the orienting motion. Caps are provided for the orienting knobs when they are not in use to preclude use of the orienting motion by mistake. Each of the three leveling screws is fitted into a threaded socket in the worm housing and attached to the base plate by means of the spring plate.

d. Base Plate Assembly. The base plate assembly is the base of the instrument when it is mounted on the tripod and it also serves as the base of the carrying case. It is a flat circular plate to which the instrument is attached by means of the spring plate. A rectangular shaped notation pad is located on the base plate and is used for recording the declination constant (para 7–11) and the vertical angle correction. An instrument fixing screw (fixed to tripod base) is threaded into a socket on the underside of the base plate assembly to attach the instrument to a tripod. The socket is kept clean and free of obstructions by a spring-loaded cover that remains closed when the instrument is not attached to the tripod. The base plate is fitted with a rubber gasket that makes a watertight seal when the cover is latched to it.

7–3. Aiming Circle Accessory Equipment

The accessory equipment for the aiming circle consists of the tripod, the carrying case cover, and

the accessory kit. The accessory kit (fig 7–5) contains the instrument light, plumb bob, lampholder and remover, and backplate and canvas cover.

a. Tripod. The tripod (fig 7–1) has three telescoping legs, an aluminum head and cover, and a carrying strap. The legs are adjusted for length and held in place by means of leg clamp wing screws. The leg hinges at the tripod head are adjusted for friction by clamping screws. The ends of the legs of the tripod are fitted with an aluminum boot and a bronze spike for ease in embedding the legs in the ground. A strap hold the legs together in the retracted position. An adjustable strap is provided for carrying the tripod when the legs are retracted and strapped together.

b. Carrying Case Cover. The cover of the carrying case is a lightweight dome-shaped aluminum cover that can be clamped to the base plate to provide a waterproof case for the instrument. The cover is provided with a carrying strap and two strong clamps for securing the cover to the base plate.

c. Backplate and Cover. The backplate and canvas cover (fig 7–5) serve as the carrying case for the instrument light, plumb bob, and lampholder and remover. The canvas cover is fastened to one of the tripod legs by two clamps.

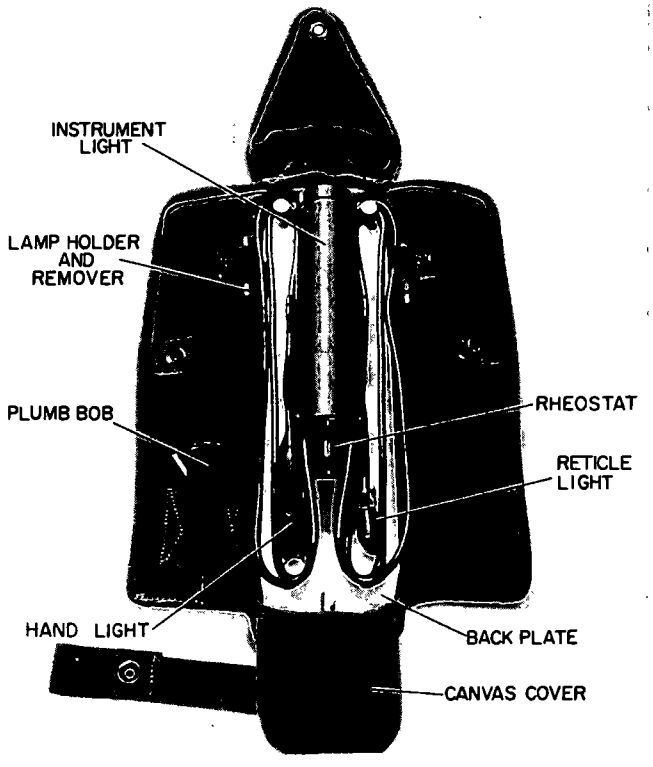


Figure 7–5. Accessory Kit.

d. Instrument Light. The instrument light consists of a battery tube containing two flashlight batteries and two flexible cords. One of these cords carries the current to the telescope through a lamp bracket assembly that fits into a machined slot on top of the telescope assembly. The other cord is attached to a hand light assembly for general illumination around the instrument (leveling and reading the scales) and to illuminate the reflector. The light intensity is regulated by a rheostat located on the end of the battery tube. The battery tube is fastened to the backplate by means of a clamp.

e. Plumb Bob. The plumb bob is suspended from a hook in the instrument fixing screw when it is used to aline the instrument over a point on the ground. When the plumb bob is not in use, it is stored in a loop in the canvas cover of the accessory kit.

f. Lampholder and Remover. The lampholder and remover is a small, rubber tubular accessory in which spare lamp bulbs are stored; it can also be used for removing burned out bulbs from their sockets.

7–4. Setting up the Aiming Circle

a. Setting Up the Tripod. The procedure for setting up the tripod is as follows:

(1) Upend the tripod and place the tripod head on the toe of the shoe. Unbuckle the restraining strap and secure the strap around the leg to which it is attached.

(2) Loosen the leg clamp wing screws and extend the tripod legs to the desired length. Tighten the leg clamp wing screws. Do not force the wing screws.

(3) Turn the tripod to its upright position and test the adjustment of each tripod leg by elevating each leg, in turn, to a horizontal position and then releasing it. If the leg is properly adjusted, it should fall to about 45° and stop. If it does not, the tripod leg should be adjusted by tightening or loosening the tripod clamping nut. The test should be repeated until successful.

(4) Spread the legs and place the tripod over the station to be occupied, with one leg approximately bisecting the angle(s) to be measured. The head of the tripod should be set up at a height which will place the telescope at a convenient height for the operator.

(5) Place the loop of the plumb bob string onto the hook of the instrument fixing screw so that the plumb bob will hang about an inch above the station. Center the tripod approximately over the station.

(6) Firmly embed the tripod legs, making sure that the plumb bob is within one half inch (laterally) of being centered over the station and that the tripod head is approximately level when the legs are embedded.

(7) Remove the tripod head cover.

b. Attaching the Aiming Circle to the Tripod. With the cover still on the instrument, attach the aiming circle to the tripod, open the spring-loaded cover on the base plate and thread the instrument-fixing screw into the socket until the aiming circle is firmly attached to the tripod. Unsnap the aiming circle cover latches, remove the cover, and hang it on the tripod head cover.

c. Plumbing and Leveling the Aiming Circle. The procedure for plumbing and leveling the aiming circle is as follows:

(1) Loosen the fixing screw slightly and carefully move the instrument around on the head of the tripod until the point of the plumb bob is centered exactly over the station.

(2) Tighten the instrument to the tripod head, making sure that the point of the plumb bob remains centered over the station.

Caution: **Excessive tightening of the fixing screw will bend the slotted arm and damage the tripod head.**

(3) Loosen the leveling screws to expose sufficient threads (⅜" to ½") on the three screws to permit the instrument to be leveled. Rotate the instrument until the axis of the tubular level vial is parallel to any two of the three leveling screws. Center the bubble by using these two leveling screws. Grasp the leveling screws between the thumb and forefinger of each hand and turn the screws simultaneously so that the thumbs of both hands move either toward each other or away from each other at the same time. This movement tightens one screw as it loosens the other. The bubble always moves in the same direction as the left thumb.

(4) Rotate the instrument 1,600 mils; this places the axis of the tubular level at right angles to the starting position. Using the third leveling screw only, center the bubble.

(5) Return the instrument to the first position ((3) above) and again center the bubble.

(6) Return the instrument to the second position ((4) above) and again center the bubble.

(7) Repeat (5) and (6) above until the bubble remains centered in both positions.

(8) Rotate the instrument 3,200 mils from the first position, placing the axis of the tubular level vial on a line parallel with the first position. If the bubble remains centered in this position, rotate the instrument 3,200 mils from the second position. If the bubble remains centered in this position, rotate the instrument throughout 6,400 mils. The bubble should remain centered; if it does, the instrument is level.

(9) If the bubble is not centered when the instrument is rotated 3,200 mils from the first position ((8) above), the level vial is out of adjustment. To compensate, move the bubble half-way back to the center of the level vial, using the same two leveling screws that were used for the first position. Rotate the instrument 3,200 mils from the second position and move the bubble half-way back to the center of the level vial, using the one remaining leveling screw. Rotate the instrument through 6,400 mils. If the bubble does not move more than one graduation, the instrument is considered level. If the bubble does not move more than one graduation, repeat the leveling procedure. If the bubble continues to displace by more than one graduation, the aiming circle should be turned in to the supporting ordnance maintenance unit for repair.

7–5. Taking Down the Aiming Circle

The procedure for taking down the aiming circle is as follows:

a. Tighten the leveling screws to their stops.

b. Check to insure that the magnetic needle is locked.

c. Cover the level vials.

d. Close the caps of the orienting knobs.

e. Place the azimuth knob over the notation pad.

f. Unhook the plumb bob and replace it in the backplate cover. Close the backplate cover.

g. Place the carrying case cover over the aiming circle and latch the cover locks.

h. Unscrew the instrument-fixing screw and remove the instrument from the tripod.

i. Replace the tripod head cover.

j. Collapse the tripod legs and tighten the wing screws.

k. Strap the tripod legs together.

7-6. Measuring Horizontal Angles

In artillery survey, horizontal angles are measured at the occupied station in a clockwise direction from the rear station to the forward station. Points for horizontal angles are always made to the lowest visible point at the rear and forward stations, and the vertical crossline is placed so that it bisects the station marker. When horizontal angles are measured with the aiming circle, two repetitions of the angle are taken and the accumulated value is divided by 2 to determine the mean value of the angle. The procedure for measuring horizontal angles is as follows:

a. Set up and level the aiming circle.

b. Zero the azimuth and micrometer scales.

c. Sight approximately on the rear station by using the lower (nonrecording) fast motion.

d. Place the vertical crossline so that it bisects the rear station at the lowest visible point by using the lower slow motion. The last motion coming onto the station should be from left to right to reduce backlash due to the play in the worm gear mechanism. Check the azimuth and micrometer scales to insure that they are still at zero. Close the orienting knob covers.

e. With the upper (recording) fast motion, rotate the aiming circle to bring the crosslines near the forward station, but keep them to the left of the station.

f. With the upper slow motion, bring the crosslines exactly to the center, at the lowest visible point, of the forward station.

g. Read and record the value of the angle on the azimuth and micrometer scales to the nearest 0.5 mil.

h. With this value still on the scales, repeat *c* through *f* above.

i. Read and record the accumulated value of two measurements of the angle to the nearest 0.5 mil.

j. To determine the mean horizontal angle, divide the accumulated value in *i* above by 2. If the accumulated value of the angle (*i* above) is smaller than the first value (*g* above), add 6,400 to the accumulated value before dividing by 2. The mean value determined should agree with the first value within 0.5 mil; if not, the angle must be remeasured.

7-7. Measuring Vertical Angles

The vertical angle to a point is measured from the horizontal plane passing through the horizontal axis of the telescope of the instrument. The vertical angle is expressed as plus or minus, depending on whether the point is above (plus) or below (minus) the horizontal plane. Usually, the vertical angle is measured each time a horizontal angle is measured. Vertical angles are measured twice and the mean value is determined. Vertical angles, if possible, are measured to the height of instrument (HI) at each forward station. The height of instrument is determined by measurement on a range pole. If the instrument operator consistently sets the instrument up at approximately the same height, then the same height of instrument on the range pole may be used throughout the fieldwork for measuring vertical angles. The procedure for measuring vertical angles is as follows:

a. Set up and level the aiming circle.

b. When the first measurement of the horizontal angle is completed (para 7-6), elevate or depress the telescope to place the horizontal crossline at the height of instrument on the forward station.

c. Read and record the value of the vertical angle to the nearest 0.5 mil. If the black numerals are used, the vertical angle is plus; if the red numerals are used, the vertical angle is minus.

d. After the second measurement of the horizontal angle is computed (para 7-6), measure the vertical angle a second time.

e. Determine the mean vertical angle and dividing the sum by 2. The mean vertical angle should agree with the first reading within 0.5 mil. If not, the angle must be remeasured.

7-8. Determining Vertical Angle Correction

To obtain correct measurements of vertical angles with the aiming circle, the horizontal axis of the telescope must lie in a true horizontal plane when the elevation scale is at zero. If it does not, a vertical angle correction (VAC) must be determined and applied to each vertical angle measured with the aiming circle. A vertical angle correction is determined at the same time that the declination constant (para 7-12) is determined. Two methods may be used to determine the vertical angle correction—the comparison method and the alternate method.

a. Comparison Method. The vertical angle between two points is measured with the aiming circle and compared with the correct vertical angle between those points. The correct vertical

angle can be determined by measurement with a theodolite or by computation, using the distance and difference in height between the points. Whenever a declination station is established (para 7–11), the vertical angle correction can be checked at the time the aiming circle is declinated. The vertical angle correction is determined by the comparison method as follows:

(1) After determining the declination constant, verify the level of the instrument. Measure the vertical angle to each azimuth mark to which the vertical angle is known. Read and record the values to the nearest 0.5 mil.

(2) Verify the level of the instrument and measure the vertical angle to each azimuth mark a second time. Record the values.

(3) Mean the vertical angles measured to each azimuth mark and compare the mean of each with the corresponding known vertical angle. Determine the differences (±). If the differences agree within 1 mil of each other, determine the mean difference to 0.1 mil and record this value on the notation pad with the declination constant (e.g., VAC + 1.6).

Note. If the differences do not agree within 1 mil, repeat (1) through (3) above.

Example:

+23.0 mils	=	known vertical angle to azimuth mark 1.
+21.5 mils	=	mean measured vertical angle to azimuth mark 1.
+ 1.5 mils	=	correction to bring measured vertical angle to known vertical angle.
— 9.0 mils	=	known vertical angle to azimuth mark 2.
—10.8 mils	=	mean measured vertical angle to azimuth mark 2.
+ 1.8 mils	=	correction to bring measured vertical angle to known vertical angle.
+ 1.5 mils	=	correction at azimuth mark 1.
+ 1.8 mils	=	correction to azimuth mark 2.
+ 3.3 ÷ 2	=	+ 1.6 mils = mean vertical angle correction.

b. Alternate Method. Two stations are established approximately 100 meters apart and properly marked. It is not necessary to know the coordinates and height of the stations or the distance between them. The aiming circle is set up at one of the stations, and the height of the instrument is measured and marked on a range pole with a pencil. The range pole is plumbed over the second station. The vertical angle to the mark on the range pole is then measured with the aiming circle. The aiming circle is then moved to the second station and set up. The height of instrument at the second station is marked on the range pole. The pole is then set up and plumbed over the first station, and the vertical angle from the second station to the first station is measured. The vertical angles measured at the two stations are compared. If they are numerically equal but have opposite signs (e.g., +0.7 and —0.7), the instrument is in correct adjustment and the vertical angle correction is zero. If the values are not numerically equal, a vertical angle correction must be determined. The correction is numerically equal to one-half of the algebraic sum of the two angles. *The sign of the correction is opposite to the sign of the algebraic sum of the two angles.* For example, if one angle were +22.0 mils and the other were —24.0 mils, the vertical angle correction would be +1.0 mil. The vertical angle correction must be applied to all vertical angle measurements made with the aiming circle.

7–9. Declination Constant

The three types of north referred to in artillery survey are true north, magnetic north, and grid north. For the purpose of artillery survey, the term "true north" is considered to be synonymous with astronomic and geodetic north. For artillery survey, all directions are established with respect to grid north. To determine grid north with an instrument equipped with a magnetic needle, first determine the angular difference between grid north and magnetic north. The clockwise angle from grid north to magnetic north is called the declination constant. It may also be called *the grid azimuth of magnetic north* (fig 7–6). The declination constant will change from month to month due to annual magnetic variations.

7–10. When To Declinate the Aiming Circle

The following rules prescribe how often and under what cirucmstances the aiming circle should be declinated:

a. The aiming circle must be declinated after an electrical storm or after receiving a severe shock, such as a drop from the bed of a truck to the ground. The magnetic needle is a delicately balanced mechanism, and any shock may cause a significant change in the declination constant for the instrument.

b. The aiming circle should be declinated when it is moved 25 miles or more from the area in which it was last declinated.

Warning: **Any move of a few meters of the aiming circle may change the relationship of grid north and magnetic north an appreciable amount as measured by the instrument due to the possibility of local magnetic attractions.**

If possible, the aiming circle should be redeclinated at every change in battery position.

c. The aiming circle should be declinated a minimum of every 30 days to determine if any changes in the instrument have occurred from accidents to the instrument which may not have been reported. If a radical change is observed, the instrument should be declinated again within a few days to determine if the observed change was due to a magnetic storm or is a real change in the characteristic of the instrument.

d. The aiming circle should be declinated when it is initially received and when it is returned from ordnance repair. Variations in the declination constant due to the time of day are not significant enough to warrant a declination at any specific time.

7–11. Declination Stations

A declination station should be established at a place that is convenient to the using units. It may be established by a field artillery battalion, division artillery, or target acquisition battalion. The declination stations should have known grid azimuths to two or more azimuth marks (at least two azimuth marks are desired, but one will suffice). For best results the azimuth marks should be at least 1,000 meters from the declination station (a minimum distance of 300 meters may be used if necessary).

a. In establishing a declination station, the direction of each azimuth mark may be determined by computing the azimuth (provided the coordinates of the declination station and the azimuth mark(s) are known), by applying a measured angle to a known direction, or by astronomic observations. The theodolite is used in measuring angles or making astronomic observations to determine the azimuth(s) for the declination station.

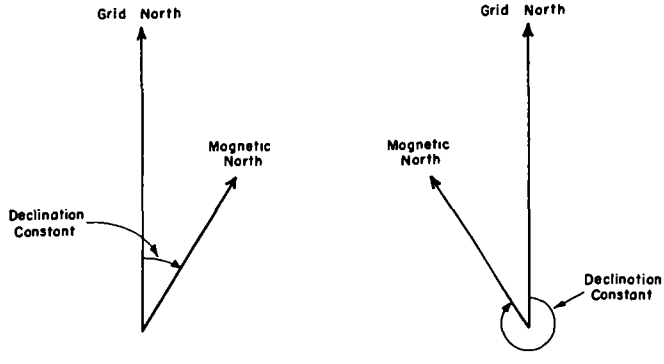


Figure 7–6. Schematic diagram illustrating the angular value which represents the declination constant.

b. Declination stations should be established in an area free from local magnetic attraction. The following minimum distances from common objects with magnetic attraction are prescribed:

Powerlines	150 meters
Electronic equipment	150 meters
Railroad tracks	75 meters
Heavy and Medium artillery, tanks	75 meters
Light artillery, trucks	50 meters
Wire fences	30 meters
Helmets, personal weapons, etc.	10 meters

c. Whenever a declination station is established, the vertical angle to each azimuth mark should be determined. The vertical angle correction for the aiming circle can then be determined at the same time it is being declinated.

d. Any survey control point with an azimuth mark may be used as a declination station provided the area is free from local magnetic attraction.

7–12. Procedure for Declinating the Aiming Circle at a Declination Station

When a declination station is available, the procedure for declinating the aiming circle is as follows:

a. Set up the aiming circle in the prescribed manner over the declination station. Level the instrument and perform the checks outlined in paragraph 7–17.

b. Set the known azimuth to the azimuth mark on the scales of the instrument and, with the lower (nonrecording) motion, sight the instrument exactly on the first azimuth mark.

c. Release the magnetic needle. With the upper (recording) motion, center the needle through the magnetic needle magnifier.

d. Read the declination constant directly from the scales (to 0.5 mil).

e. Relevel the aiming circle; repeat the steps in *b* through *d* above using the second azimuth mark if it is available; if it is not available use the first azimuth mark again.

f. Compare the two values determined for the declination constant. If they agree within 2 mils, determine the mean value and record it (to the nearest mil) on the notation pad of the aiming circle. If the two values differ more than 2 mils, repeat the entire procedure.

7–13. Procedure for Declinating the Aiming Circle When a Declination Station Is Not Available

In rapidly moving situations, time may not permit the establishment of a declination station. Under such circumstances, the aiming circle is declinated as follows:

a. Select a point on the ground that is identifiable on the map and is suitable for a declination station. Place the aiming circle over this point and prepare it for declination by leveling it and performing the checks in paragraph 7–17.

b. Select two distant points that can be identified on the map and scale the direction from the occupied point to each selected distant point on the map.

c. Use the direction scaled from the map and declinate the instrument by following the procedure in paragraph 7–12.

d. Compare the two values determined for the declination constant. They *must* agree within 10 mils.

e. If the values determined for the declination constant agree within 10 mils, determine the mean value and record it (to the nearest mil) on the notation pad of the aiming circle. If the values do not agree within 10 mils, repeat the entire procedure.

f. A declination constant determined in this manner must be verified at the first opportunity.

7–14. Determining Grid Azimuth With Aiming Circle

A declinated aiming circle can be used to determine a grid azimuth. The procedure for determining a grid azimuth is as follows:

a. Set up and level the aiming circle in the prescribed manner.

b. Using the upper motion, set the declination constant on the scales of the instrument.

c. Release the magnetic needle and center it, using the lower motion. This will aline the 0–3200 line with grid north.

d. Lock the magnetic needle.

e. Using the upper motion, rotate the instrument and sight on the desired point.

f. Read and record the measured grid azimuth as indicated on the scales of the aiming circle to the nearest 0.5 mil.

g. Repeat the procedure and determine the grid azimuth a second time. If the two azimuth determinations agree within 2 mils, mean and record the measured grid azimuth to the nearest 0.1 mil. If they do not agree, repeat the entire procedure.

7–15. Orienting the Aiming Circle by Magnetic Compass on a Required Azimuth

A declinated aiming circle can be oriented on a required grid azimuth by use of the magnetic needle. The procedure for orienting on a required azimuth is as follows:

a. Set up and level the aiming circle in the prescribed manner.

b. Using the upper motion, set the declination constant on the scales of the instrument.

c. Release the magnetic needle and center it, using the lower motion.

d. Lock the magnetic needle.

e. Using the upper motion, set the required grid azimuth on the scales of the instrument. The scope of the instrument is now oriented on the required azimuth.

7–16. Care of the Aiming Circle

Proper care of an instrument will prolong its life and insure better results to the user. Listed below are several precautions which should be observed while the aiming circle is being used.

a. Screw Threads. To prevent damage to the screw threads do not tighten the adjusting, clamping, or leveling screws beyond a snug contact.

b. Lenses. The lenses should be cleaned only with a camel hair brush and lens tissue. The brush should be used first to remove any dust or other abrasive material from the lenses, and then the lens should be cleaned with the lens tissue. Any smudge spots remaining on the lens after the lens tissue is used can be removed by slightly moistening the spot and again cleaning with the lens tissue. Care should be taken not to scratch the lens or remove the bluish coating. The bluish coating reduces the glare for the observer.

c. Tripod Head. The tripod head should be wiped clean of dirt and moisture and should be examined for nicks or burrs before the instrument is attached to the tripod.

d. Magnetic Needle. The magnetic needle should be locked when not in use.

e. Azimuth Knob. The azimuth knob should be positioned over the notation pad before the instrument is put into its case.

f. Worm Gears. Movement of the worm gears should never be forced. In disengaging the fast motion of the azimuth mechanism, be sure that the gear is free before the instrument is rotated. To reengage the worm gear, move the instrument back and forth slightly, until the gear of the azimuth mechanism meshes with that of the lower (nonrecording) motion.

g. Lubrication. The aiming circle should not be lubricated by unit personnel. All parts requiring lubrication are enclosed and should be lubricated only by qualified instrument repair personnel. The instrument should be checked periodically by an ordnance maintenance unit.

h. Cleaning. The instrument should be kept clean and dry. Metal parts should be cleaned of grease and oil with mineral spirits paint thinner and then wiped dry. Care must be taken to insure that the threads of the leveling screws are clean and turn easily. The polished surfaces should be given a thin coat of light grade aircraft instrument lubricating oil to prevent rust. Electrical parts should be cleaned with trichlorethylene. Rubber parts, other than electrical parts, should be cleaned with warm soapy water. After the rubber parts are dry, a coating of powdered technical talcum should be used to preserve the rubber. Canvas should be cleaned with a dry brush or by scrubbing with a brush and water.

7–17. Maintenance Checks and Adjustments

Maintenance checks should be made as described in *a* through *e* below. If any check, other than the micrometer adjustment check in *c* below, indicates that adjustment is necessary, the aiming circle should be turned in to the supporting ordnance maintenance unit for repair. The checks in *a* through *e* below should be performed before the instrument is used.

a. Level Vial Check. After the aiming circle has been set up and leveled, rotate the instrument through 6,400 mils. If the bubbles in the horizontal plate level vials (circular and tubular) do not remain centered, the instrument should be turned in for repair at the first opportunity.

b. Titled Reticle Check. After the aiming circle has been set up and leveled, place the vertical crossline on some well-defined point. Elevate and depress the telescope. If the vertical crossline moves off the point as the telescope is elevated or depressed, the instrument should be turned in for repair.

c. Micrometer Adjustment Checks. The only adjustments that may be made by using unit personnel are the adjustments of the micrometers so that they read zero when the main scales with which they are associated read zero.

(1) *Checking and adjusting the azimuth micrometer.* The azimuth micrometer is checked and adjusted as follows:

(*a*) Set the zero of the azimuth scale opposite the index mark.

(*b*) If the zero of the azimuth micrometer is opposite the index, no adjustment is necessary. If the zero is not opposite the index, loosen the screws on the end of the azimuth knob and slip the micrometer scale until the zero is opposite the index.

(*c*) Hold both the azimuth knob and the micrometer scale in position and tighten the azimuth knob screws.

(*d*) Check to insure that the zero of both the azimuth scale and the micrometer scale are still opposite their respective index marks after the screws are tightened.

(2) *Checking and adjusting the elevation micrometer.* The elevation micrometer is checked and adjusted as follows:

(*a*) Set the zero of the elevation scale opposite the index mark.

(*b*) If the zero of the elevation micrometer is opposite the index, no adjustment is necessary. If the zero is not opposite the index, loosen the screws on the end of the elevation knob and slip the elevation micrometer scale until the zero is opposite the index.

(*c*) Hold both the elevation knob and the micrometer scale in position and tighten the micrometer knob screws.

(*d*) Check to insure that the zero of both the elevation scale and the micrometer scale are still opposite their respective index marks after the screws are tightened.

d. Level Line Check. The purpose of the level line check is to determine whether correct values are obtained when vertical angles are measured with the aiming circle. If correct vertical angle values are not obtained with the instrument and there is not adequate time to turn the instrument

in for repair, vertical angle correction should be determined. The performance of the level line check and the procedure for determining a vertical angle correction are discussed in detail in paragraph 7–8. After the elevation micrometer check (*c*(2) above) has been performed and any necessary adjustments have been made, the level line check must be performed before a vertical angle is measured with the aiming circle.

e. Magnetic Needle Check. To check the magnetic needle, set up and level the aiming circle. Release the magnetic needle and center it in the reticle of the magnetic needle magnifier. To test the needle for sluggishness, move an iron or steel object back and forth in front of the aiming circle to cause the needle to move on its pivot. Permit the needle to settle. If the needle does not return to center in the reticle, the instrument should be turned in for repair. This check should be performed prior to using the magnetic needle to establish a direction or to orient the instrument.

Section II. THEODOLITE, 0.2 MIL

7–18. General

There are, at present, two models of the theodolite, Directional Type, 0.2 mil (T–16 and Model 901) in the field. The nomenclature, operating, care and adjustment procedures covered in this section are basically standard for both of these models. The 0.2 mil theodolite (fig 7–7) is a compact, lightweight, dustproof, optical-reading, direction-type instrument equipped with a horizontal circle (repeater) clamp. It is used to measure horizontal angles and to determine vertical angles for artillery fifth-order survey. The horizontal and vertical scales of the theodolite are inclosed and are read by means of a built-in optical system. The scales, graduated in mils, can be read directly to 0.2 mil and by estimation to the nearest 0.1 mil. The scales may be illuminated by either sunlight or artificial light.

The 0.2 theodolite is issued with a canvas accessory kit, a compass, eyepiece prisms, sun filters, a sunshade, two jeweler's screwdrivers, two adjusting pins, a camel-hair brush, a lubricant, a plastic instrument head cover, two operation and service manuals, a battery case with lighting devices and three spare bulbs, and a universal tripod with plumb bob, plug-in sleeve, and tripod key in a leather pouch attached to the tripod.

7–19. Nomenclature of the 0.2 Mil Theodolite

a. Tribrach. The tribrach is the lower part of the instrument, which is fastened to the tripod head (fig 7–7). It is that part of the theodolite which contains the three leveling screws and the circular level. The leveling screws are completely inclosed and dustproof. The tribrach is detachable from the theodolite and is secured to the theodolite by three tapered locking wedges controlled by the tribrach clamp lever.

b. Horizontal Circle Housing. The horizontal circle housing assembly, the center portion of the theodolite, contains the horizontal circle; the vertical axis assembly; the receptacles, contacts, and connections for electric illumination; and the three spike feet for securing the theodolite to the tribrach. The following controls are located on the horizontal circle housing:

(1) *Horizontal circle clamp.* The horizontal circle clamp is located on the upper part of the horizontal circle housing and is beneath the telescope eyepiece when the telescope is in the direct position. This clamp is used by the operator to lock the horizontal plate to the alidade in any given position for orienting the instrument.

(2) *Horizontal clamping screw.* The horizontal clamping screw is located on the side of the horizontal circle housing. This control locks the alidade in any desired position about its vertical axis.

c. Alidade. The alidade, the upper part of the theodolite, includes the telescope and microscope assemblies and the vertical circle assembly. Located on the alidade are the following:

(1) *Levels.* The theodolite has a plate level and vertical circle level (split bubble) in addition to the circular level on the tribrach. The plate level is located at the bottom of the opening between the standards on the alidade and is graduated to aid the operator in the precise leveling of the instrument. The vertical circle level is completely built in and is located adjacent to the vertical circle.

(2) *Telescope.* The 28-power telescope of the 0.2 mil theodolite can be rotated vertically about the horizontal axis of the theodolite. Objects appear inverted when viewed through the telescope. The reticle of the telescope (fig 7–8) is etched on glass and consists of horizontal and vertical cross-

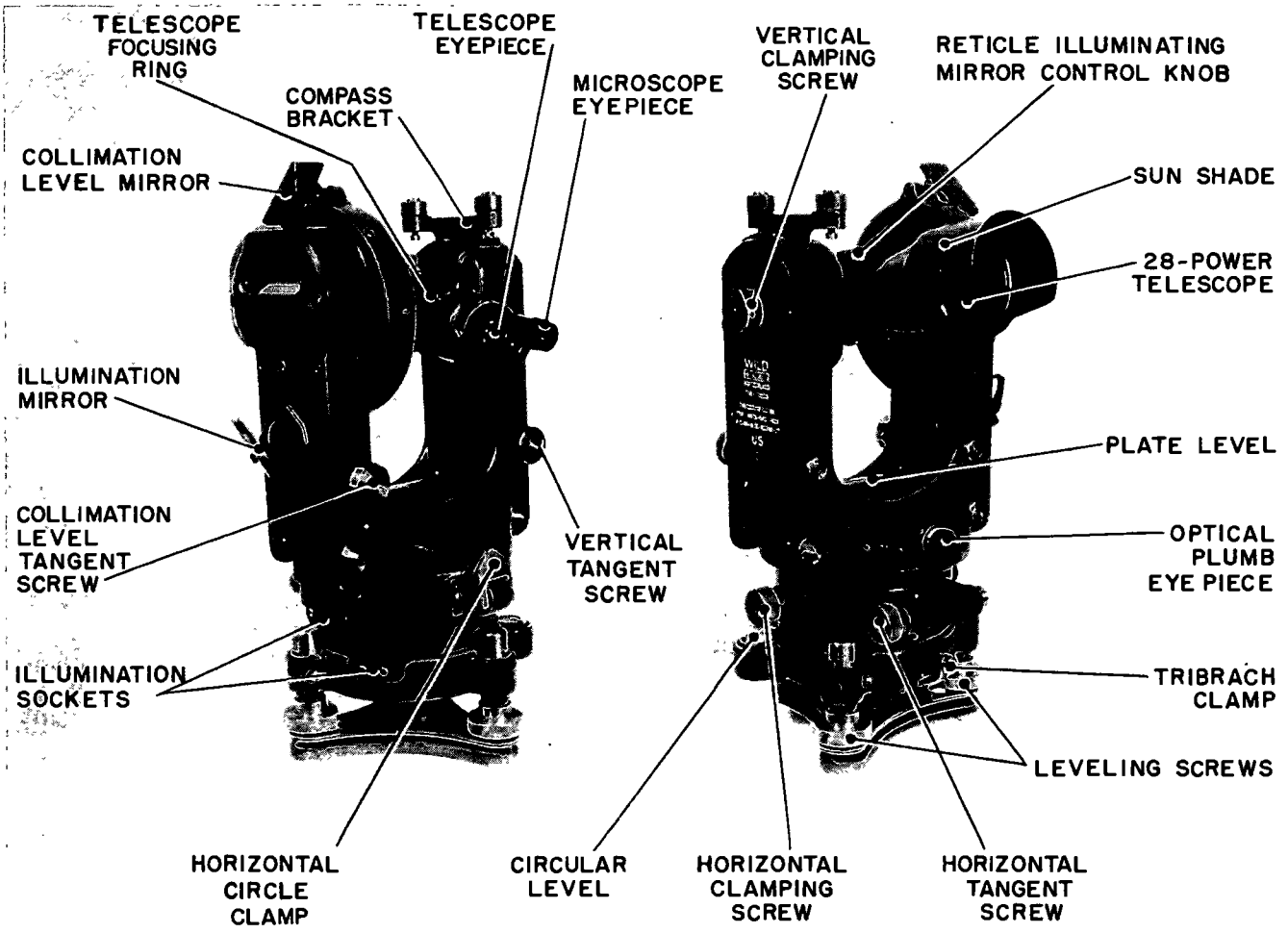


Figure 7–7. 0.2 mil theodolite.

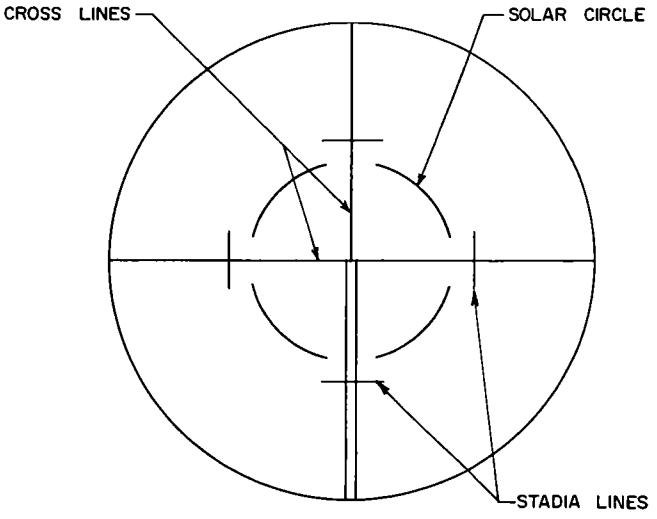


Figure 7–8. Telescope reticle.

lines, a solar circle for making pointings on the sun, and stadia lines. The reticle crosslines are focused by rotating the telescope eyepiece; the image, by rotating the knurled focusing ring. Two horizontal pull action screws are provided for correcting the horizontal collimation error (para 7–34). A knob located on top of the telescope controls a small mirror inside the telescope for illuminating the reticle when electric illumination is used.

(3) *Circle-reading microscope.* Attached to the telescope is a microscope for viewing the images of the horizontal and vertical circles. A segment of both circles is presented in the microscope, with the horizontal circle (marked "Az") appearing below the vertical circle (marked "V"). The image of the circles is brought into focus by rotating the knurled microscope eyepiece.

(4) *Illumination mirror.* A tilting mirror is located on the side of the standard below the vertical circle for illuminating the horizontal and vertical circles during daylight operations. The intensity of the light on the circles can be adjusted by rotating and tilting the mirror until proper light-

ing is achieved. For night operations, this mirror is removed and replaced by a lamp assembly.

(5) *Vertical clamping screw.* The vertical clamping screw is located on the standard opposite the vertical circle. This control allows the telescope to be rotated vertically about its axis or to be locked in a fixed vertical position.

(6) *Vertical tangent screw.* The vertical tangent screw is located on the lower portion of the same standard as the vertical clamping screw. This control provides precision adjustment in the vertical positioning of the telescope.

(7) *Collimation level tangent screw.* The collimation level tangent screw is located below the vertical circle and on the same standard. This control is used for precise leveling of the vertical circle level (split bubble) by bringing the image of the ends of this bubble into coincidence. A tilting mirror is provided above the vertical circle for viewing the position of the bubble.

(8) *Optical plumb.* An optical plumb system is provided on the theodolite for centering the instrument over a station. The optical plumb is a small prismatic telescope that contains either a small circle or crosslines as a reticle, depending on the model. The focus of the optical plumb telescope is adjusted by rotating or pulling out the sleeve of the knurled eyepiece located in the base of the alidade.

d. Carrying Case. The carrying case for the 0.2 mil theodolite consists of a base plate and a steel, dome-shaped hood. When mounted in the base, the instrument rests on supports by means of four studs and is locked to the supports by two clamping levers. A desiccant is located in the base plate. A padded wooden box is also furnished for transporting the theodolite.

e. Accessory Equipment.

(1) *Electric illumination device.* An electric illumination device is issued with the 0.2 mil theodolite. In the lower housing of the theodolite that fits into the tribrach is a socket for a connector plug from the battery case. A second socket in the horizontal circle housing is connected to the first socket by an internal contact ring. A connector plug is inserted in the second socket to accommodate a plug-in lamp, which replaces the illumination mirror. When the current is on, this lamp illuminates both circles, both the horizontal and vertical level vials, and the telescope reticle. A rheostat is provided on the battery case for adjusting the intensity of the light. A hand lamp is attached to a second cord from the battery case and is used to provide general illumination around the instrument.

(2) *Diagonal eyepieces and sun filter.* Standard equipment includes diagonal eyepieces that screw directly into the telescope and the reading microscope eyepieces. A sun filter is provided for the telescope eyepiece.

(3) *Compass.* A circular compass is issued as an accessory item for the 0.2 mil theodolite. When the circular compass is used, it is mounted in the compass bracket located on top of the standard opposite the vertical circle. The compass is used only to provide a rough check on an azimuth, to orient the sketch in the field notes, or to obtain a direction for assumed control (chap 15). The compass should always be placed in the pocket of the accessory case with the dial down to prevent breaking the cover glass.

f. Tripod. The universal tripod is issued with the theodolite. This tripod has extension legs and an accessory case. The accessory case is made of leather and is mounted on the tripod with wood screws. The case contains a plumb bob with a plug-in sleeve and a wrench for the tripod legs.

7–20. Setting Up the Theodolite

a. Setting up the Theodolite. The tripod used with the 0.2 mil theodolite is similar to that used with the aiming circle M2. The same procedure is used for setting up the tripod (para 7–2) except that for the theodolite, the plug-in sleeve of the plumb bob is inserted into the instrument-fixing screw.

b. Removing the Theodolite from its Case. To remove the theodolite from its case—

(1) Grasp the carrying strap with both hands just above the two clamping levers and pull outward to release the clamping levers from the base assembly.

(2) Lift the dome-shaped cover directly off the instrument and lay it to one side.

(3) Pull upward on the two base clamping levers that secure the theodolite to the base assembly. Grasp the theodolite by the standard that has the trademark inscribed on it (right standard) and lift the theodolite off the base. The theodolite should be handled by the right standard only at all times.

(4) Attach the instrument to the tripod head by screwing the fixing screw snugly into the base of the tribrach.

(5) Replace the cover on the base of the case

to prevent dust and moisture from entering the case. Move case away from the tripod to provide working area for instrument operator.

c. Plumbing and Leveling the Theodolite. The procedure for plumbing and leveling the 0.2 mil theodolite is the same as that for the M2 aiming circle (para 7–4) except that after the instrument is leveled, the plumb bob is removed and placed in its case. The optical plumb is then checked to insure that the instrument is centered exactly over the station. If it is not, center the instrument over the station by shifting it on the tripod head, and again check the level of the instrument. If necessary, repeat the leveling process and again check the optical plumb. Repeat this process until the instrument is level and centered over the station.

7–21. Taking Down the Theodolite

When observations are completed at a station, the theodolite and tripod are march ordered as follows:

a. Place the telescope in a vertical position with the objective lens down and lightly clamp the vertical clamping screw.

b. Turn each leveling screw approximately halfway down and to same height.

c. Position the horizontal clamping screw directly over one of the leveling screws and lightly clamp it.

d. Grasp the instrument by its right standard and unscrew the instrument-fixing screw. Lift the theodolite from the tripod and secure it in the carrying case. Replace the dome-shaped cover.

e. Replace the tripod head cover, collapse the tripod, and strap the tripod legs together.

7–22. Reading and Setting Horizontal and Vertical Circles

a. With the 0.2 mil theodolite prepared for observing as described in paragraph 7–20, open the illumination mirror and adjust the light so that both the horizontal and vertical circles are uniformly illuminated when viewed through the circle-reading microscope. Adjust the focus of the microscope until the image of the circles appears sharp and distinct.

b. When the circles are viewed through the circle-reading microscope (fig 7–9), the vertical marked "V") appears above the horizontal circle (marked "Az"). Both circles are graduated from 0 to 6,400 mils with a major graduation each 10 mils. Unit mils and tenths are viewed on an auxiliary scale graduation in 0.2 mil increments from 0 to 10 mils. Circle readings are estimated to the nearest 0.1 mils. The scale reading is taken at the point where the major (10 mil) graduation (gageline) is superimposed on the auxiliary scale. When the telescope is not in a horizontal position, the scales will appear to be tilted, with the amount of tilt depending on the inclination of the telescope.

c. All horizontal angle measurements with the 0.2 mil theodolite should be started with an initial reading of 1.0 mil on the horizontal circle. For practical purposes, this reading precludes working with a mean of the direct and reverse (D&R) pointings on a starting station of less than 0 mil. To set this value on the horizontal circle, release the horizontal clamping screw and rotate the instrument until the major graduation 0 appears on the horizontal circle. Clamp the horizontal clamping screw and use the horizontal tangent screw to set the 0 gageline directly over the 1.0 mil graduation on the auxiliary scale. Firmly engage the horizontal circle clamp by folding it downward. The horizontal circle is now attached to the alidade of the instrument, and the reading of 1.0 mil will remain on the horizontal circle regardless of the direction in which the instrument is pointed.

7–23. Focusing the Telescope To Eliminate Parallax

Before the theodolite is used for measuring angles, the telescope must be focused to eliminate parallax by bringing the focus of the eyepiece and the focus of the objective lens to the plane of the reticle (crosslines). This is accomplished as follows: Point the telescope toward the sky or a neutral background and rotate the knurled ring on the telescope eyepiece until the reticle crosslines are sharp, distinct lines. (In doing this, the observer should be very careful to focus his eyes on the crosslines, not the sky.) Next, point the telescope toward a well-defined distant point and, still focusing the eye on the crosslines, bring the distant point into a clear, sharp image by rotating the knurled focusing ring on the telescope. Use the horizontal tangent screw to center the vertical crossline on the point. To check for elimination of parallax, move the eye horizontally back and forth across the eyepiece. If the parallax has been eliminated, the crossline will remain fixed on the object as the eye is moved. If all parallax has not been eliminated, the crossline will appear to move back and forth across the object. To eliminate any remaining parallax, change the focus of the eyepiece

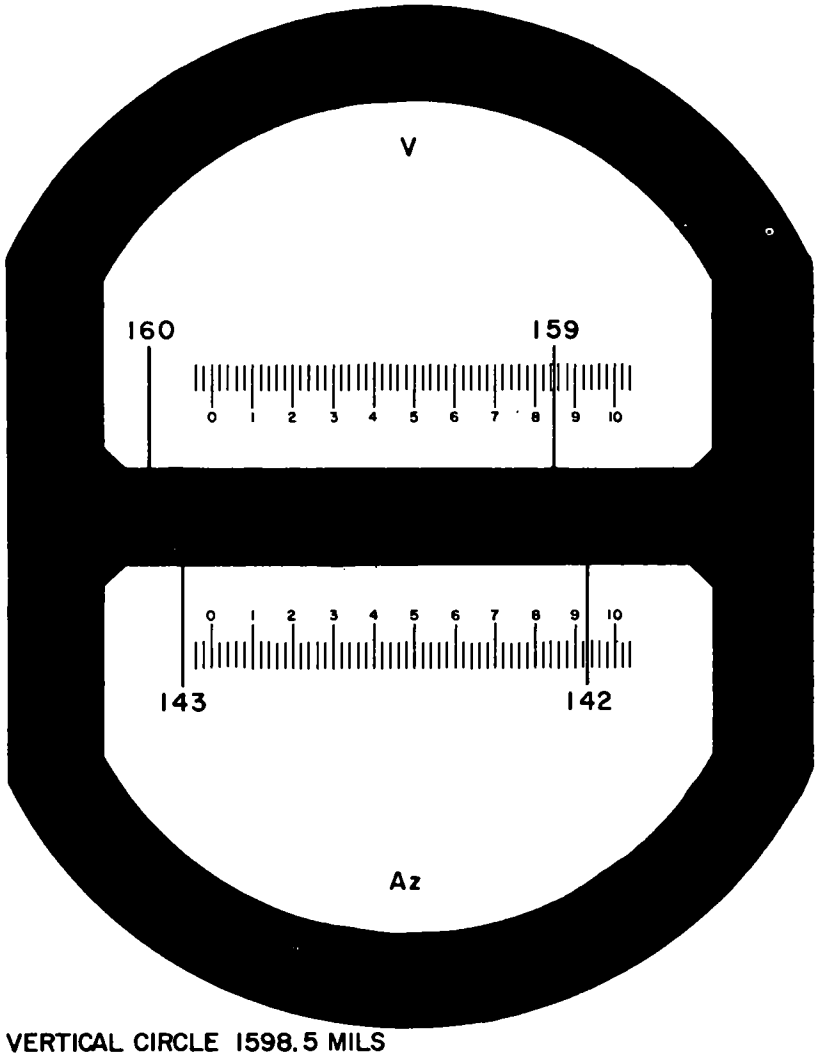


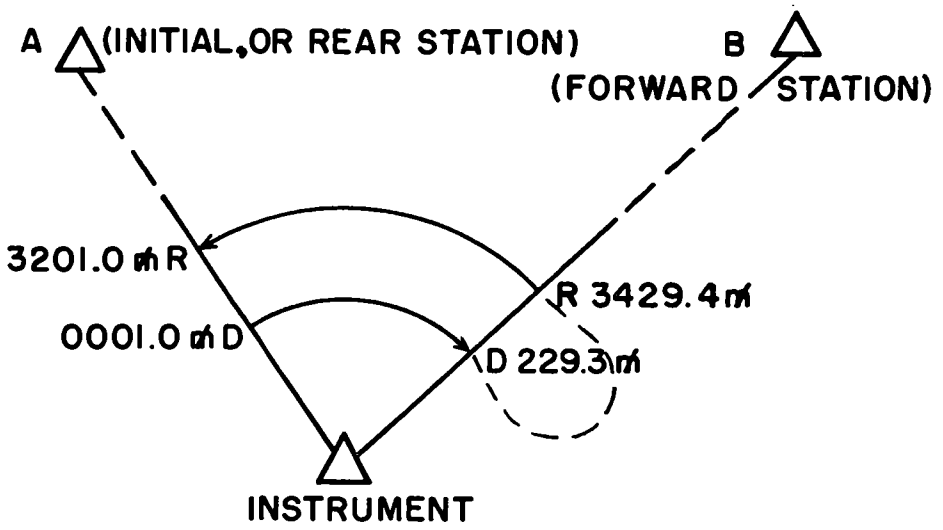
Figure 7–9. 0.2 mil theodolite scales viewed through the circle-reading microscope.

slightly to bring the crosslines into sharper focus, and refocus the telescope accordingly until there is no apparent motion. Each time an angle is to be measured, the telescope should be focused to eliminate parallax, since accurate points with the instrument are not possible if parallax exists.

7–24. Measuring Horizontal Angles

a. In artillery survey, the 0.2 mil theodolite is used as a direction-type instrument, and the horizontal circle clamp is used only to set the initial circle setting (1.0 mil) on the horizontal circle prior to making a pointing on the initial station. The method of measuring horizontal angles consists of determining, at the occupied station, the horizontal circle readings to each observed station, beginning with an initial (rear) station. The angle between two observed stations is the difference between the mean horizontal circle readings determined for each of the observed stations. The mean horizontal circle readings used to determine the angles are determined from two points (circle readings) on each observed station (fig 7–10).

b. With the telescope in the direct (D) position, the initial circle setting of 1.0 mil on the horizontal circle, and the horizontal circle clamp down, a pointing is made on the initial station. This establishes the direction of the station at 1.0 mil with respect to the horizontal circle. The value of the direct reading on station A is recorded in the field notes (fig 7–10). Release (up) the horizontal circle clamp; this causes the horizontal circle to detach itself from the alidade and remain in its fixed position. A pointing is then made on each station



STATION	T	HORIZONTAL ∠ MILS	MEAN	VERTICAL READING	VERTICAL ∠
A	D	0001.0			
	R	3201.0	0001.0		
INST	MN	228.4			+1.4
B	D	229.3		1598.5	+1.5
	R	3429.4	229.4	4801.4	+1.4

Figure 7–10. Extract from field notebook and sketch of pointings in measuring horizontal angles.

around the horizon in a clockwise sequence. After the pointing is made on the last station, the telescope is plunged to the reverse (R) position, and pointings are made on each station in a counterclockwise sequence, beginning with the last station and ending with the initial station.

c. When points are being made, the horizontal and vertical clamping screws (fast motion) are used to place the crossline approximately on the object marking the station. The horizontal and vertical tangent screws are then used to place the crosslines exactly on the object. The final direction of rotation of the tangent screws must be clockwise.

d. The telescope should be plunged to the direct position after the reverse pointing on the initial station has been made and the horizontal circle reading recorded. A direct pointing should then be made on the initial station. Although it is not a part of the angle measurement, the instrument will be approximately zeroed in order to save time in setting the initial circle setting for the next angle measurement at the next station.

7–25. Determining Verticle Angles

a. Normally, each time a horizontal angle is measured, a vertical angle to the forward station is determined. If possible, vertical angles are determined to the height of the instrument (HI).

b. Vertical angles cannot be measured directly with the theodolite. The vertical circles of the theodolite reflect readings of 0 mil at the zenith, (straight up) 1,600 mils horizontal direct, 3,200 mils at nadir (straight down), and 4,800 mils hor-

izontal reverse. Hence, the values read from the vertical circle are not vertical angles but are zenith distances that must be converted to vertical angles. When the collimation level bubble is centered, vertical circle readings are taken from what is, in effect, an upward extension of the plumbline of the theodolite (fig 7–11).

One value of the vertical angle is computed from the vertical circle reading obtained with the telescope in the direct position and pointed at the station. With the telescope in the direct position, a vertical circle reading of less than 1,600 mils indicates that the station observed is above the horizontal plane of the theodolite and the vertical angle is plus; a vertical circle reading greater than 1,600 mils indicates that the station observed is below the horizontal plane of the theodolite and the vertical angle is minus. The value of a plus vertical angle is determined by subtracting the vertical circle reading from 1,600 mils (∢ #1, fig 7–11. The value of a minus vertical angle is determined by subtracting 1,600 mils from the vertical circle reading (#2, fig 7–11). A second value of the vertical angle is computed from the vertical circle reading obtained with the telescope in the reverse position and pointed at the station. With the telescope reversed, a vertical circle reading greater than 4,800 mils indicates a plus vertical angle and a vertical circle reading less than 4,800 mils indicates a minus vertical angle. The value of a plus vertical angle is determined by subtracting 4,800 mils from the vertical circle reading (∢ #3, fig 7–11), and the value of a minus vertical angle is determined by subtracting a vertical circle reading from 4,800 mils (∢ #4, fig 7–11). The two values of the vertical angle are then meaned to obtain the vertical angle to the observed station.

c. After the crosslines have been placed on the station, the telescope is elevated (or depressed) until the horizontal crossline is exactly on the

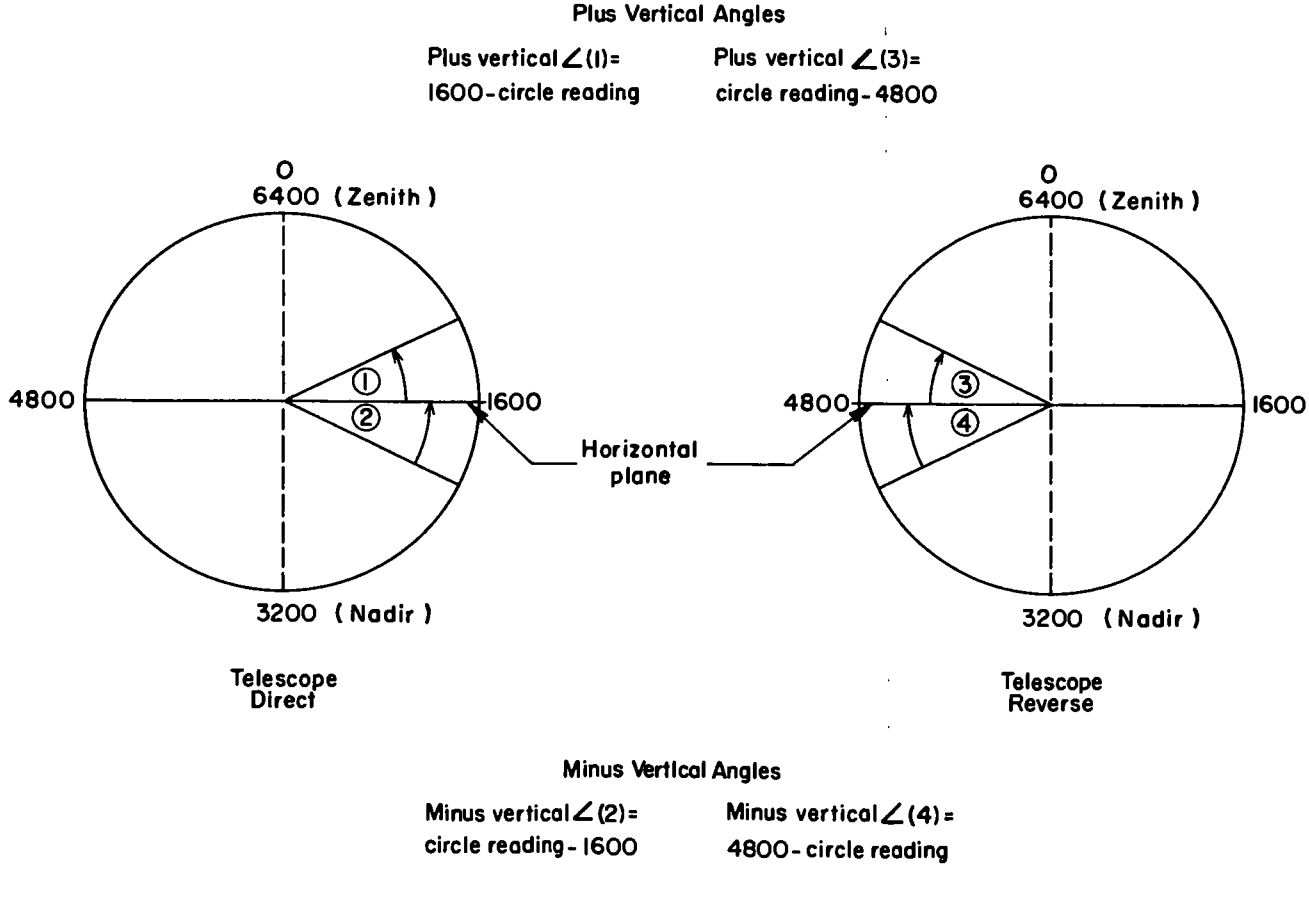


Figure 7–11. Vertical angles from vertical circle readings.

point to which the vertical angle is desired. After the telescope is positioned on the station, the bubble of the collimation level (split bubble) is centered on its vial by rotating the collimation level tangent screw until the images of the ends of the bubble coincide (fig 7–12). A vertical circle reading is then read in the circle-reading microscope.

7–26. Computing Horizontal and Vertical Angles

a. After the direct and reverse points have been made and the horizontal and vertical circle readings recorded in the field notes (fig 7–10), the size of the angles are determined. To determine the horizontal angle between stations A and B (fig 7–10), the mean of the points on each station are first determined by mentally adding or subtracting 3,200 mils from the reverse reading and then taking the mean of the direct and reverse readings. The results are entered in the field notes in the appropriate column. The horizontal angle between the stations is then determined by obtaining the difference in the mean circle readings. In figure 7–10, the mean pointing on station A is 0001.0 mil; on station B, 229.4 mils. Therefore, the horizontal angle from station A to station B is 228.4 mils (229.4 — 1.0 = 228.4).

b. In the field notes in figure 7–10, the direct pointing on station B resulted in a vertical circle reading of 1,598.5 mils, or a vertical angle of +1.5 mils. With the telescope reversed, the vertical circle reading on station B was 4,801.4 mils, or a vertical angle of +1.4 mils. Hence, rounding this value to the nearest even 0.1 mil, the mean vertical angle from the instrument to station B is +1.4 mils ($1.5+1.4=\frac{2.9}{2}=1.45$ rounded to 1.4).

7–27. Care of the Theodolite

The 0.2 mil theodolite is a delicate instrument, and care must be taken not to drop it or bump it against any object. If the instrument gets wet, it must be dried before it is stored in the carrying case. As soon as possible, the instrument should be placed in a dry room or tent. It should be removed from the carrying case so that it may dry completely. If left in the closed carrying case, it will absorb the humidity in the air if there is an increase in temperature. Should the temperature drop afterwards, the moisture will condense on the interior of the instrument and may render the instrument inoperative. In moving the instrument from station to station, a man on foot may carry the instrument, mounted on the tripod, with the tripod under one arm and a hand supporting the theodolite itself. All motions should be clamped with the telescope in the vertical position. When the theodolite is carried over rough terrain, the instrument should be transported in its carrying case. When transported in a vehicle, the theodolite should be in the carrying case, and the case should be in the padded box. For short distances in vehicles, the carrying case may be held in an upright position on the lap of the instrument operator.

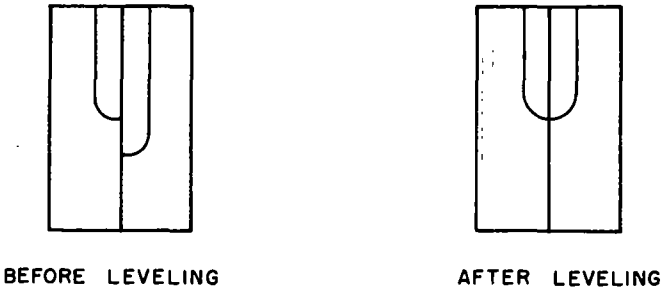


Figure 7–12. View of collimation level.

7–28. Cleaning the Theodolite

The theodolite must be kept clean and dry. During use, as necessary, and after use, the instrument should be cleaned as follows:

a. Painted surfaces should be wiped with a clean cloth.

b. The lenses should be cleaned only with a camel-hair brush and lens tissue. The lens should be cleaned first with the brush to remove any dust or other abrasive material and then with the lens tissue. Any smudge spots remaining after the lens tissue is used can be removed by slightly moistening the spot and again cleaning with the lens tissue. Care should be taken not to scratch the lens or remove the coating. The coating reduces glare for the observer.

c. All metal parts of the tripod should be cleaned with a cloth moistened with an approved cleaning solvent and wiped dry. The wooden parts should be cleaned with a soft cloth moistened with water and dried thoroughly. The leather strap should be cleaned with a suitable leather cleaner.

7–29. Repair of the Theodolite

Adjustment (except as explained in para 7–30 through 7–35) and repair of the 0.2 mil theodolite must be performed by qualified instrument repair personnel. Theodolites in need of major adjustment or repair should be turned in to the engineer unit responsible for providing maintenance service. TM 5–6675–200–15 (T–16) and TM

5-6675-234-15 (M901) outline the categories of maintenance.

7-30. Adjustment of the Theodolite

a. The theodolite must be kept in correct adjustment if accurate results are to be obtained. There are four tests and adjustments of the 0.2 mil theodolite that should be made periodically by the instrument operators. The adjustments are performed in the sequence in which they are discussed in paragraphs 7-31 through 7-34. When a test indicates that an adjustment is necessary, this adjustment should be made and the instrument tested for accuracy before the next test is made.

b. The four tests and adjustments of the theodolite are made with the instrument mounted on its tripod. For these tests and adjustments, the instrument should be set up in the shade on firm ground with the head of the tripod as nearly level as possible. The theodolite should be protected from the wind.

c. If handled properly, an instrument will remain in adjustment indefinitely. The adjustments should be made only by qualified personnel, and they should be made in a deliberate, careful manner. Needless and excessive movement of the adjusting screws will cause the screws to become worn, and the instrument will not hold an adjustment.

7-31. Plate Level Adjustment

a. Purpose. The purpose of the plate level adjustment is to make the vertical axis of the theodolite truly vertical when the plate level bubble is centered within its vial (fig 7-13).

b. Test. To test the adjustment of the plate level, place the axis of the bubble parallel to any two of the three leveling screws. With these two leveling screws, center the bubble. Rotate the instrument 1,600 mils and again center the bubble, using only the third leveling screw. Repeat these two steps until the bubble remains centered in both positions. Carefully center the bubble in the first position, and then rotate the instrument 3,200 mils. If the bubble does not remain centered, adjustment is required. The discrepancy noted in the position of the bubble is the apparent error, or twice the actual error, of the plate level.

c. Adjustment. To adjust the plate level, use the adjusting pin and remove one-half of the apparent error (actual error) by turning the capstan adjusting screw, which is recessed in the right standard 1½ inches above the horizontal clamping screw. Repeat the test to detect and adjust, if necessary, any error remaining in the adjustment of the plate level. The plate level is in proper adjustment when the bubble remains centered throughout 6,400 mils.

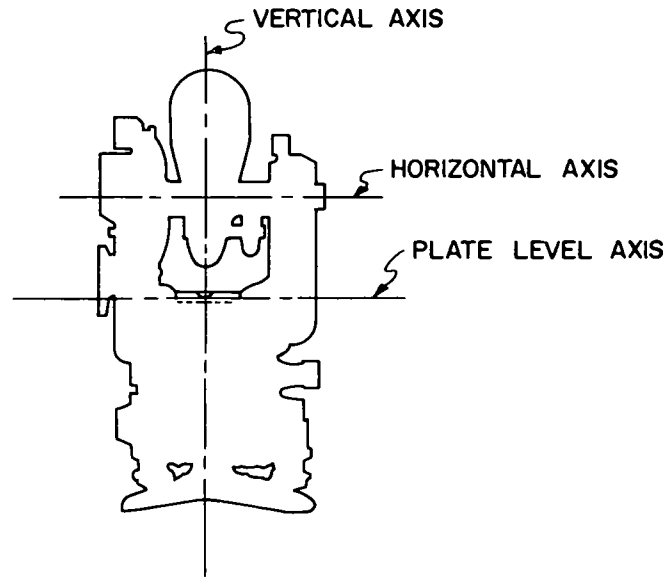


Figure 7-13. Plate level adjustment.

7-32. Optical Plumb Adjustment

a. Purpose. The purpose of the optical plumb adjustment is to aline and center the optical plumb in the vertical axis of rotation of the theodolite when the theodolite is properly leveled and the station mark is centered in the reticle of the optical plumb (fig 7-14).

b. Test. To test the optical plumb, set up the instrument over a station that is clearly marked by a cross or other well-defined point and accurately level the instrument. The image of the point should be centered exactly on the crosshair, or in the center of the circle depending on which model is used. Rotate the instrument 3,200 mils about its vertical axis. If the image of the point does not remain centered in the reticle, the amount of displacement is the apparent error, or twice the actual error, of the optical plumb.

c. Adjustment. To adjust the optical plumb, one-half of the displacement (the actual error) is corrected by turning the two optical plumb adjusting screws. Access to the adjusting screws is obtained by removing the cover screws, located 1¼ inches to the right and left of the optical plumb eyepiece. By very small movements of the screws, the image of the reticle is moved one-half of the distance toward the station mark. (The last movement of the adjusting screws must be clockwise to compress a counterspring). Check the adjustment

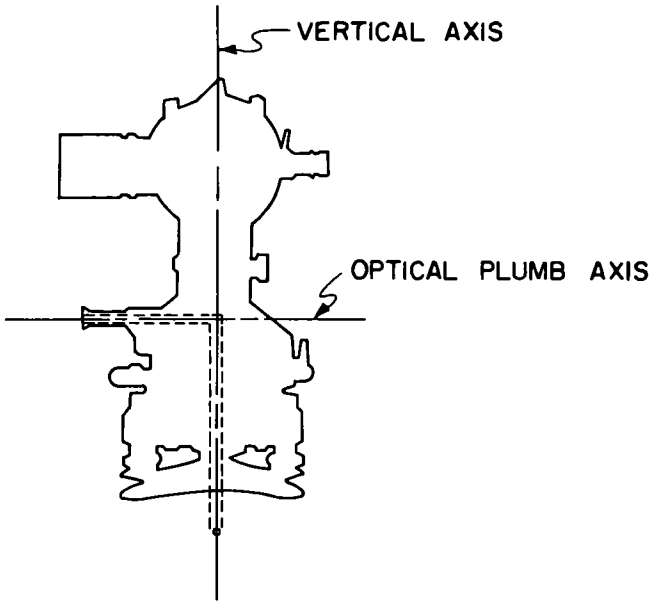


Figure 7–14. Optical plumb adjustment.

by again leveling and centering the instrument over the station mark and then rotating the instrument through 6,400 mils while watching the point on the ground through the optical plummet eyepiece. If the image of the reticle does not remain centered on the station mark throughout the circle, repeat the adjustment. After the adjustment is completed, replace the cover screws.

7–33. Horizontal Collimation Adjustment

a. Purpose. The purpose of the horizontal collimation adjustment is to make the line of sight perpendicular to the horizontal axis of the telescope (fig 7–15).

b. Test. To test the horizontal collimation, select a well-defined point at least 100 meters from the instrument and at approximately the same height as the instrument. With the telescope in the direct position, center the vertical crossline on the selected point and read the horizontal circle. Plunge the telescope to the reverse position and take a second reading on the same point. The instrument operator should repeat both readings to insure that no error was made in reading the instrument. These two readings should differ by 3,200 mils. Assuming no error in the pointings or readings, any discrepancy between the actual differences in the two readings and 3,200 mils is the apparent error, or twice the horizontal collimation error. If this discrepancy exceeds plus or minus 1 mil, the horizontal collimation adjustment should be performed.

c. Adjustment. For the purpose of illustration, assume that the horizontal circle reading in the direct position is 150.7 mils and in the reverse position is 3,352.9 mils. With the telescope in the direct position and using the horizontal tangent screw, set the circle to the mean value of the direct and reverse pointings (151.8). In doing so, the vertical crossline of the telescope reticle is moved off the point. Move the vertical crossline back to the point by turning the two pull-action capstans adjusting screws that are arranged horizontally and on opposite sides of the telescope near the eyepiece. If the reticle must be moved to the right, loosen the left screw slightly and tighten the right screw a corresponding amount. To move the crosshair to the left, loosen the right screw first and tighten the left screw. If the adjusting screw is tightened an excessive amount, it will cause the retical to get out of adjustment later on. *DO NOT OVERTIGHTEN.* Proceed in this manner, loosening and tightening in small amounts until the crosshair is exactly on the sighted point. Do not try to cover the entire distance in one step. Repeat the test to insure that the proper adjustment has been made.

Note. This adjustment can also be made with the telescope remaining in the reverse position and using the mean value for the reverse pointing; i.e., 3,351.8.

7–34. Vertical Collimation Adjustment

a. Purpose. The purpose of the vertical collimation adjustment is to make the line of sight hori-

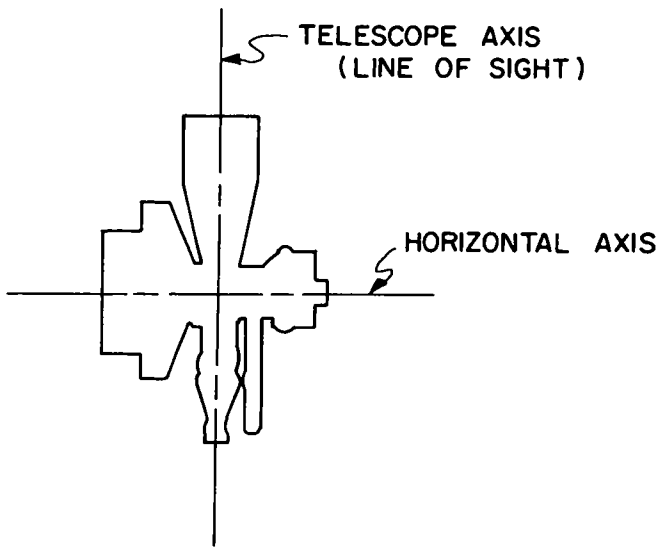


Figure 7–15. Horizontal collimation adjustment.

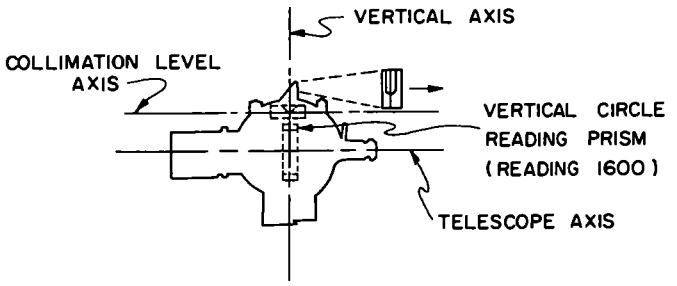


Figure 7–16. Vertical collimation adjustment.

zontal when the vertical circle reads 1,600 mils with the telescope in the direct position (4,800 mils with the telescope in the reverse position) and the ends of the collimation level bubble in alinement (fig 7–16).

b. Test. To test the vertical collimation, select a well-defined point at least 100 meters from the instrument and about on horizontal line with the theodolite. With the telescope in the direct position, take a vertical circle reading on the point, making sure that the collimation level bubble is precisely alined. Plunge the telescope to the reverse position and again take a vertical circle reading to the same point. The collimation level bubble must be precisely alined before, and checked after, each vertical circle reading. Repeat these two measurements to insure that no error was made. The sum of the direct and reverse readings should equal 6,400 mils. Any difference between the sum of the two readings and 6,400 mils is the apparent (index) error, or twice the collimation level error. If the difference exceeds plus or minus 1 mil, the collimation level should be adjusted.

c. Adjustment. To adjust the vertical level, compute the correct vertical circle reading by applying one-half of the index error of the vertical circle to the direct reading. If the sum of the two readings is greater than 6,400 mils, subtract one-half the index error from the direct reading; if the sum is less than 6,400 mils, add one-half of the index error to the direct reading. Place the instrument in the direct position and accurately sight on the point. With the telescope sighted on the point, use the collimation level tangent screw to place the correct reading on the vertical circle scale. With the telescope sighted on the point and the correct reading on the vertical circle scale, the collimation level bubble will not be centered. Bring the split bubble into coincidence by turning its adjusting screw. Access to the adjusting screw is gained by removing the cover of the vertical circle level. Repeat the test to insure that the proper amount of adjustment has been made.

Example:

Vertical circle reading for direct pointing	1,479.3
Vertical circle reading for reverse pointing	4,919.5
Sum	6,398.8

Apparent (index) error = 6,400 — 6,398.8 = 1.2 mils
Collimation error = 1.2 ÷ 2 = 0.6 mil
Correct vertical circle reading (direct) — 1,479.3 + 0.6 = 1,479.9

With the telescope in the direct position, accurately sight on the point. Use the collimation level tangent screw and place the correct reading (1,479.9) on the vertical circle scale. Bring the split bubble into coincidence by turning its adjusting screw.

Note. This adjustment also can be made with the telescope in the reverse position, using the mean value for the reverse pointing; i.e., 4,919.5 + 0.6 = 4,920.1 mils

7–35. Verticality Adjustment

The 0.2 mil theodolite is constructed so that the vertical crossline remains vertical, and no adjustment is required. For other adjustments, see paragraph 7–53 *a*, *b*, and *d*.

Section III. THEODOLITE 0.002 MIL

7–36. General

a. The 0.002 mil theodolite (fig 7–17) is the authorized angle-measuring instrument for artillery fourth-order survey. The theodolite, having only one spindle, is a direction-type instrument and is used to measure horizontal angles and to determine vertical angles. It has interior scales which are read by means of a built-in optical system. The scales, graduated in mils, are readable directly to 0.002 mil and by estimation to the nearest 0.001 mil. The scales may be illuminated by sunlight or by means of a built-in wiring system using artificial light. All components of the instrument which can be seriously damaged by dust or moisture are inclosed.

b. Some troop units may be equipped with another model, the sexagesimal (1-second) theodolite, to use for artillery fourth-order survey. The two models are identical except for the graduation of the horizontal and vertical scales. The scales of the sexagesimal theodolite are graduated in degrees, minutes, and seconds and can be read directly to 1 second.

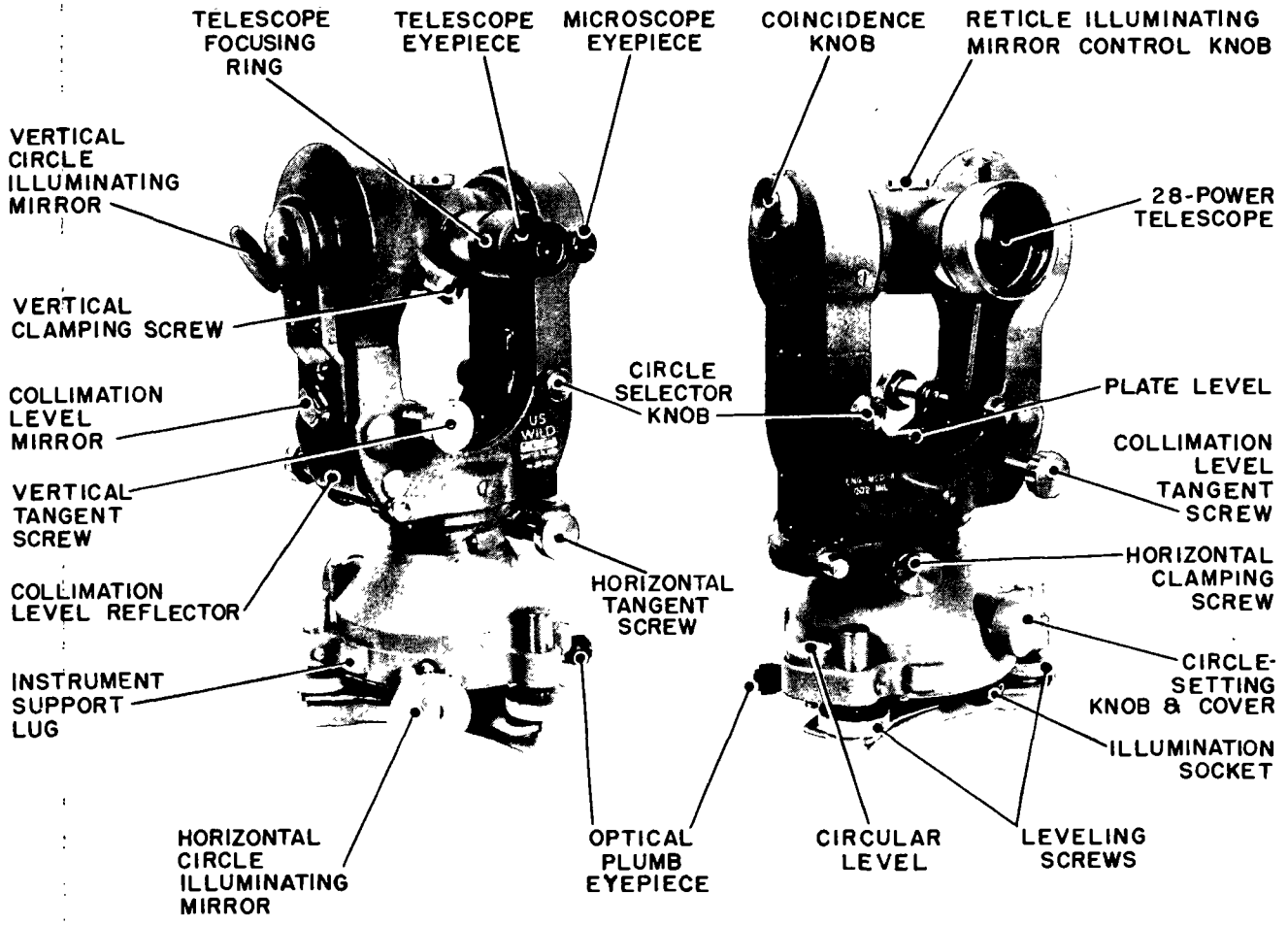


Figure 7–17. The 0.002 theodolite.

c. The 0.002 mil theodolite is issued with a canvas accessory case containing an instructional pamphlet, diagonal eyepieces for the telescope and reading microscope, a sun filter, a jeweler's screwdriver, two adjusting pins, a camel-hair brush, a plastic instrument head cover, two lamp fittings for artificial illumination; a battery case containing lighting devices and spare bulbs; and a universal tripod with a plumb bob, plug-in sleeve, and tripod key in a leather pouch attached to the tripod. The accessories of some models of the theodolite are stored in the base of the carrying case.

7–37. Nomenclature of the 0.002 Mil Theodolite

a. Tribrach. The tribrach is that part of the theodolite which contains the three leveling screws and the circular level. The leveling screws are inclosed and dustproof. On models manufactured subsequent to 1956, the tribrach is detachable. On these models, the tribrach is secured to the theodolite by three tapered locking wedges controlled by the tribrach clamp lever. An optical plumb system is located in the tribrach for accurately centering the theodolite (either model) over a station.

b. Horizontal Circle Housing. The horizontal circle housing assembly contains the horizontal circle, the vertical axis assembly, prisms for illuminating and reading the horizontal circle, contacts, and connections for electrical illumination. The following items are located on the horizontal circle housing:

(1) *Circle-setting knob and cover.* The circle-setting knob, located on the side of the horizontal circle housing, is used to rotate the horizontal circle to any desired position. The cover of the circle-setting knob is provided to prevent the operator from disturbing the orientation of the horizontal circle by an accidental touch. The cover should be closed at all times except when the horizontal circle is being oriented.

(2) *Illumination mirror.* A hinged, tilting mirror to illuminate the horizontal circle is located

on the lower portion of the horizontal circle housing. The intensity of the light on the horizontal circle can be adjusted by rotating and tilting the mirror until the circle is properly lighted. For artificial illumination, this mirror is removed and replaced by a plug-in lamp.

(3) *Instrument support lugs.* Three rectangular shaped instrument support lugs are uniformly spaced around the base of the horizontal circle housing. These lugs are used to secure the theodolite to the base of the carrying case. The plug-in socket which receives the battery box cable for artificial illumination is located immediately above one of the lugs.

c. Alidade. The alidade is the upper (rotating) part of the theodolite. It includes the telescope and microscope assemblies and the two standards that support them, the vertical circle assembly, and the horizontal clamp assembly. Located on the alidade are the following:

(1) U-*standard assembly.* The U-standard forms the support for all the components making up the upper part of the instrument and includes the horizontal circle axle and flange, the circle selector knob and prism, and the horizontal axis prism.

(2) *Levels.* The theodolite has a plate level and a vertical circle level (split bubble) in addition to the circular level on the tribrach. The plate level is located at the bottom of the opening between the standards and is graduated to aid the operator in the precise leveling of the instrument. The vertical circle level is completely built in and is located adjacent to the vertical circle.

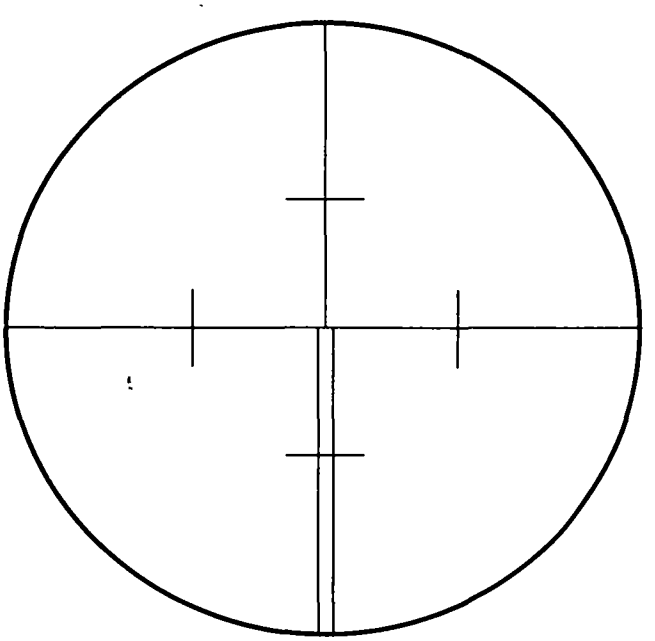


Figure 7–18. Telescope reticle.

(3) *Collimation level tangent screw.* The collimation level tangent screw is located below the vertical circle and on the same standard. This control is used for precise leveling of the vertical circle level (split bubble) by bringing the images of the ends of the bubble into coincidence. A prism on the side of the standard is provided for viewing the position of the bubble. Below the prism, a hinged reflector is rotated outward to provide illumination of the vertical circle level.

(4) *Telescope.* The 28-power telescope of the 0.002 mil theodolite can be rotated vertically about the horizontal axis of the theodolite. Objects appear inverted when viewed through the telescope. The reticle of the telescope (fig 7–18) is etched on glass and consists of the horizontal and vertical crosslines, stadia lines, and on later models, a solar circle. The reticle crosslines are focused by rotating the telescope eyepiece; the image, by rotating the knurled focusing ring.

Three adjusting screws are provided for correcting the horizontal collimation error. A knob located on top of the telescope controls a small mirror inside the telescope for illuminating the reticle when electric illumination is used.

(5) *Circle selector knob.* The circle selector knob is located immediately above the trademark inscription. The knob is inscribed with a heavy black line which indicates whether the image of the horizontal or the vertical circle is visible in the circle-reading microscope. When the line is horizontal, the horizontal circle may be viewed; when the line is vertical, the vertical circle may be viewed.

(6) *Circle-reading microscope.* Attached to the telescope is a microscope for viewing the horizontal and vertical circles. The circle to be viewed is selected by turning the circle selector knob to either the horizontal or the vertical position. The field of view of the microscope appears to contain two small windows. The upper window contains images of two diametrically opposite portions of the horizontal and vertical circle. One of the images of the circle is inverted and appears above the other image of a portion of the micrometer scale. The image of the scale is brought into focus by rotating the knurled microscope eyepiece.

(7) *Coincidence knob.* The coincidence knob on the side of the right standard is used to obtain readings for either the horizontal or vertical circle in conjunction with the micrometer scale. It oper-

ates the micrometer scale to bring the vertical or horizontal circle graduation into coincidence.

(8) *Illumination mirror.* A tilting mirror for illuminating the vertical circle is located on the side of the standard at the center of the vertical circle. This mirror is identical with the mirror on the horizontal circle in construction and use.

(9) *Horizontal clamping screw.* The horizontal clamping screw is located on the right front portion of the instrument immediately above the horizontal circle housing. This control is used to lock the alidade in any desired position on its vertical axis.

(10) *Horizontal tangent screw.* The horizontal tangent screw is located on the right rear portion of the instrument immediately above the horizontal circle housing. This control enables precision adjustment in the horizontal positioning of the telescope.

(11) *Vertical clamping screw.* The vertical clamping screw is located adjacent to the vertical circle. This control permits the telescope to be rotated vertically about its axis or to be locked in a fixed position.

(12) *Vertical tangent screw.* The vertical tangent screw is immediately below the vertical clamping screw. This control permits precision adjustment in the vertical positioning of the telescope.

d. Carrying Case. The carrying case for the 0.002 mil theodolite consists of a base plate and steel dome-shaped hood. When the theodolite is placed on the base plate, it rests on three supports and is secured to the supports by three clamps. A padded wooden box is also furnished for transporting the theodolite in its carrying case.

e. Electric Illumination Device. The 0.002 mil theodolite contains a built-in wiring system for illuminating the circles, the micrometer scale, and the telescope reticle. Two bulb holders are in the base of the carrying case. Each of the circle-illuminating mirrors can be replaced by pulling a mirror off the instrument and inserting a bulb holder in its place. A battery case is attached to one of the tripod legs, and the wiring from this case leads to an electric illuminating plug located in the tribrach. A second wire from the battery case leads to a hand lamp that is used for general illumination around the instrument. A rheostat is provided on the battery case for adjusting the intensity of light. Telescope reticle illumination is adjusted by turning the reticle illumination knob on top of the telescope to rotate a small mirror located at the horizontal axis in the telescope.

f. Tripod. The universal tripod is issued with the theodolite. This tripod has extension legs and accessory case. The overall length of the closed tripod is 3 feet; the extended length is 5.2 feet. The accessory case is made of leather and is mounted on the tripod. The case contains a plumb bob with a plug-in sleeve and a wrench for the tripod legs. The head of the tripod is covered with a screw-on protector cap.

7–38. Preparing the Theodolite for Use

a. Setting up the tripod. The tripod used with the 0.002 mil theodolite is similar to that used with the aiming circle. The procedure for setting up this tripod is the same as that for the 0.2 mil theodolite (para 7–20).

b. Removing the Theodolite From its Case. The 0.002 mil theodolite is removed from its case in the same manner as the 0.2 mil theodolite (para 7–20*b*), except that it is fastened to the base by three supports with locking devices.

c. Plumbing and Leveling the Theodolite. The procedure for plumbing and leveling the 0.002 mil theodolite is the same as that for the 0.2 mil theodolite (para 7–20*c*).

d. Focusing the Telescope to Eliminate Parallax. The telescope of the 0.002 mil theodolite is the same as the telescope of the 0.2 mil theodolite and it is focused to eliminate parallax in the same manner (para 7–23).

e. Taking Down the Theodolite. The 0.002 mil theodolite is taken down and placed in its carrying case in the same manner as the 0.2 mil theodolite (para 7–21).

7–39. Circle Readings

a. A system of lenses and prisms permits the observer to see small sections of diametrically opposite sides of either the horizontal circle or the vertical circle (fig 7–19). The circles are viewed through the circle-reading microscope located alongside the telescope.

The circle to be viewed is selected by turning the circle selector knob on the right standard. The field of view of the circle reading microscope contains two small windows (fig 7–20). The upper window shows images of two diametrically opposite portions of the circle (horizontal or vertical). One image of the circle is inverted and appears

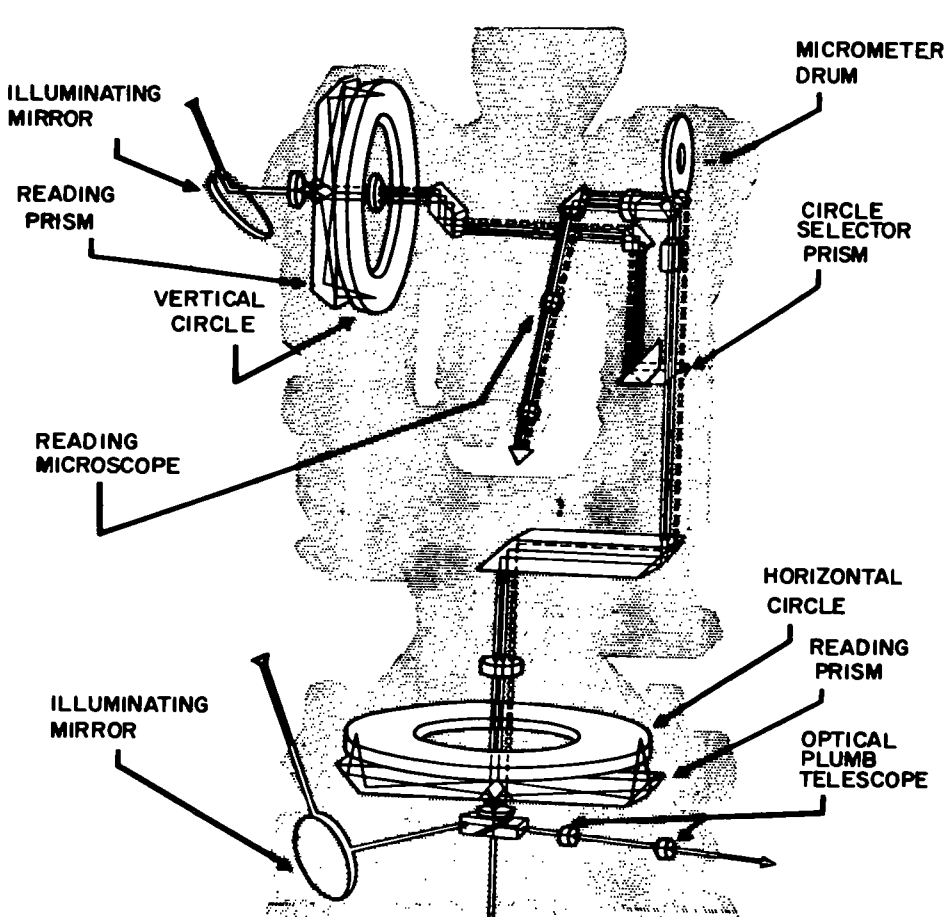


Figure 7-19. Circle-reading optical system of the 0.002 mil theodolite.

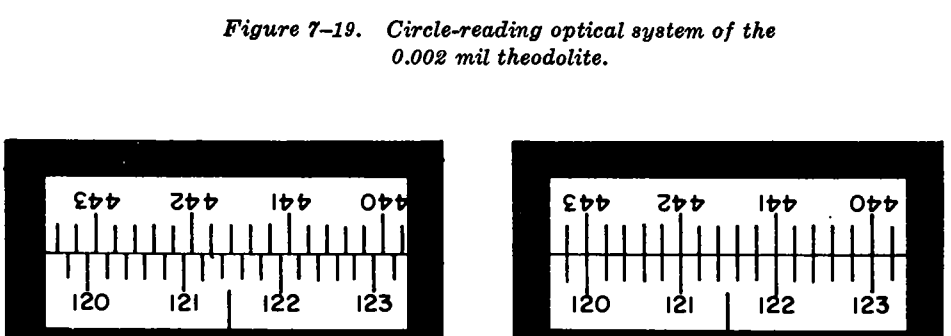


Figure 7-20. 0.002 mil theodolite scales viewed through the circle-reading microscope.

above the other image. The lower window shows an image of a portion of the micrometer scale.

b. The coincidence knob on the side of the right standard is used to obtain readings for either of the circles in conjunction with the micrometer scale. Optical coincidence is obtained between diametrically opposite graduations of the circle by turning the coincidence knob. When this knob is turned, the images of the opposite sides of the circle appear to move in opposite directions across the upper window in the circle-reading microscope. The image of the micrometer scale in the lower window also moves.

The graduations of the circle (upper window) are brought into coincidence so that they appear to form continuous lines across the dividing line. The center of the field of view in the upper window is marked by a fixed vertical index line. The final coincidence adjustment should be made between circle graduations in the vicinity of this index line.

7–40. Horizontal Circle Readings

To determine a reading on the horizontal circle—

a. Rotate the circle selector knob until the black line on the face of the knob is horizontal.

b. Adjust the illuminating mirror so that both windows in the circle reading microscope are uniformly lighted.

c. Focus the microscope eyepiece so that the graduations of the circle and micrometer scale are sharply defined.

d. Observe the images in the microscope. Bring the circle graduations into coincidence at the center of the upper window by turning the coincidence knob. The final motion of the coincidence knob must be clockwise.

e. Read the horizontal circle and micrometer scale.

7–41. Steps in Circle Reading (Mil)

On the 0.002 mil theodolite, the main scale (upper window) is graduated in 2-mil increments (fig 7–20). Each fifth graduation is numbered, omitting the unit digits; e.g., 10 mils appears as 1 : 250 mils as 25; and 3,510 mils as 351. The micrometer scale (lower window) is graduated from 0.000 mil to 1.000 mil. Each 0.002 mil is marked with a graduation, and each fifth graduation is numbered (hundredth of a mil). The scale may be read to 0.001 by interpolation. The steps in reading the circles are as follows:

a. Bring the circle graduations into coincidence (para 7–40) and determine the first erect numbered graduation to the left of the index line that marks the center of the upper window. This numbered graduation indicates the value of the circle reading in tens of mils. In figure 7–20, this value is 121.

b. Locate on the inverted scale the graduation for the number diametrically opposite 121 (the number ±320). In figure 7–20 this number is 441 (viewed ⟨illegible⟩). The inverted number normally is to the right of the index line which marks the center of the field of view. (When the unit mils of the circle reading is zero, coincidence is obtained with the circle reading and its diametrically opposite number in coincidence with each other to the left of the index line). Both values always end in the same number—in this case, the number is 1.

c. Count the number of spaces between graduations from 121 to the inverted 441. There are five spaces, representing 5 mils. Each of these spaces represents 1 mil.

d. Convert 121, which is tens of mils, to 1,210 mils and, to this value, add the unit mils determine in *c* above (1,210 + 5 = 1,215 mils, the angular value obtained from the main scale).

e. On the micrometer scale (lower window), the index line that marks the center of the field of view also indicates the value to be read from the micrometer scale. In figure 7–20, this value is 0.475 mil.

f. Add the values determined to *d* and *e* above (1,215 + 0.475) = 1,215.475 mils, the angular value displayed in figure 7–20.

7–42. Steps in Circle Reading (Sexagesimal)

On the sexagesimal (1 second) theodolite, the main scale (upper window) is graduated in 20-minute intervals, and every third graduation is numbered to indicate a degree. The micrometer scale (lower window) is graduated in minutes and seconds from 0 seconds to 10 minutes. The scale may be read to 1 second.

The steps in reading the circles are as follows (fig 7–21):

a. Bring the circle graduations into coincidence (para 7–40) and determine the first erect numbered graduation to the left of the index line that marks the center of the upper window. This numbered graduation indicates the value of the circle

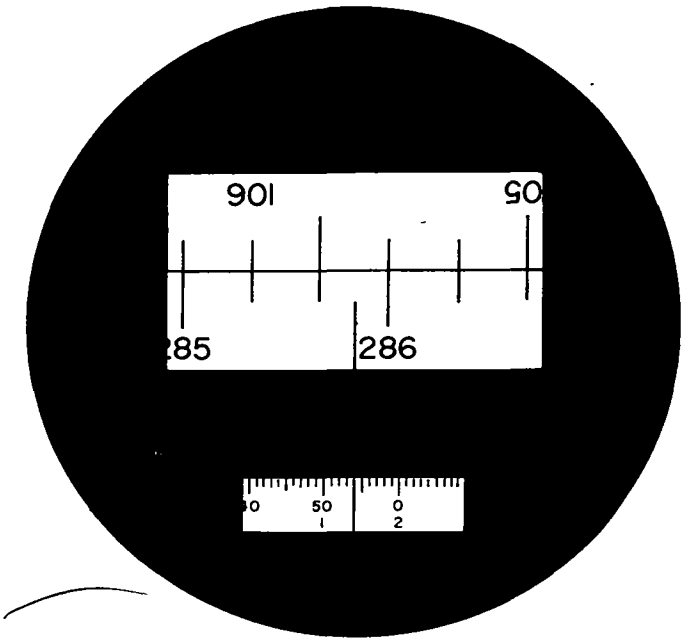


Figure 7–21. 1 second theodolite scales viewed through the circle-reading microscope.

reading in degrees. In figure 7–21, this value is 285°.

b. Locate the inverted graduation which differs from 285° by 180°; this value is 105 (viewed 901). The inverted number is always to the right of the index line which marks the center of the field of view. (When the tens of minutes of the circle reading is zero, coincidence is obtained with the circle reading and its diametrically opposite number in coincidence with each other to the left of the index line.) Both values always end in the same number—in this case, the number 5.

c. Count the number of spaces between the graduations from 285 to the inverted 105. Each space represents 10 minutes. In figure 7–21, there are five spaces, representing 50 minutes.

d. The angular value obtained from the main scale (upper window) is 285° 50′ (285° + 50′ = 285° 50′).

e. The index line which marks the center of the field of view in the lower window indicates the value to be read on the micrometer scale. This scale has two rows of numbers below the graduations, the bottom row being the unit minutes and the top row seconds. In figure 7–21, the unit minutes and seconds are read as 1′54″.

f. Add the angular values determined in *d* and *e* above (285° 50′ + 1′ 54″ = 285° 51′ 54″, the angular value).

7–43. Vertical Circle Readings

The circle selector knob is rotated until the black line on the face of the knob is vertical. The vertical circle may now be viewed in the circle-reading microscope. A reading on the vertical circle is made in the same manner as a reading on the horizontal circle.

7–44. Setting the Horizontal Circle

There are two situations in which it is necessary to set the horizontal circle.

a. In the first instance, the horizontal circle is to be set to read a given value with the telescope pointed at a target. The initial circle setting of 0.150 (± 0.100 mil) is used as an example.

(1) Point the instrument at the target.

(2) Using the coincidence knob, place a reading of 0.150 on the micrometer scale.

(3) Using the circle-setting knob, zero the main scale as accurately as possible, insuring that the numbered lines, which are 3,200 mils apart (the erect 0 graduation and the inverted 320 graduation) are touching each other.

(4) With the coincidence knob, bring the main scale graduations into a more precise coincidence.

(5) Read the horizontal circle. The reading should be 0.150 (within± 0.100 mil).

b. In the second instance, it is desired to orient the instrument on a line of known direction from a reference direction (or measure a predetermined angle).

(1) Point the instrument on the line for which the reference direction is provided and read the circle.

(2) Add the angular difference between the reference direction and the desired direction (or the predetermined angle) to the circle reading. The result is the circle reading for the instrument when it is pointed in the desired direction.

(3) Using the coincidence knob, set the micrometer scale to read the fractional portion of the desired circle reading to the thousandth of a mil.

(4) Using the horizontal clamping screw and the horizontal tangent screw, rotate the alidade to obtain coincidence on the main scale at the mils value corresponding to the reading obtained in (2) above. When coincidence is obtained, the instrument is pointing in the desired direction.

7-45. Measuring Horizontal Angles

a. Since the 0.002 mil theodolite is a direction-type instrument, the values of horizontal angles are determined by differences in circle readings. The procedures for measuring and determining horizontal angles (fig 7-22) are as follows:

(1) With the telescope in the direct (D) position, point to station A and record the initial circle setting (0.166 mil).

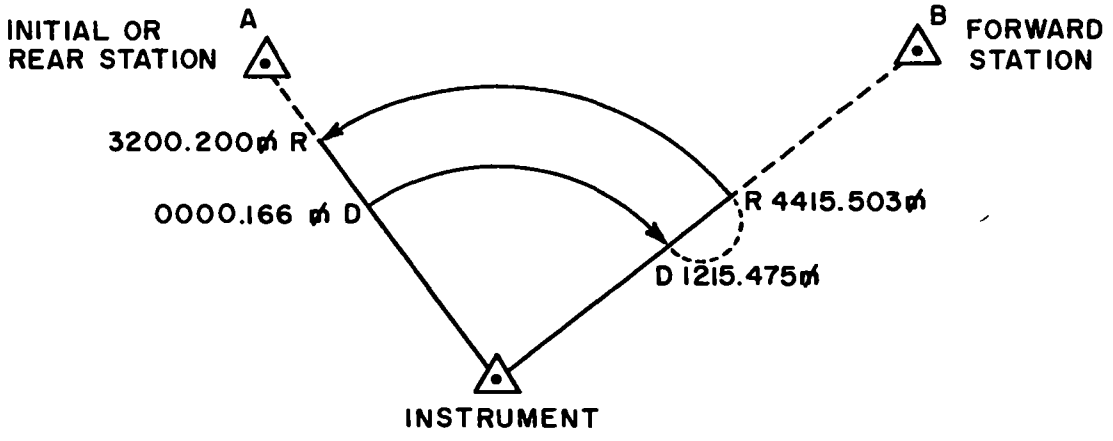
(2) With the telescope in the direct (D) position, point to station B and record the circle reading (1,215.475 mils).

(3) Plunge the telescope to the reverse (R) position, point to station B and record the circle reading (4,415.503 mils).

(4) With the telescope in the reverse (R) position, point to station A and record the circle reading (3,200.200 mils).

(5) Subtract 3,200 mils from the reverse pointing on station A and mean the remainder with the direct pointing on station A (0.183 mil).

(6) Subtract 3,200 mils from the reverse pointing on station B and mean the remainder



STATION	T	HORIZONTAL ∠ MILS	MEAN	VERTICAL READING	VERTICAL ∠ MILS
A	D	0000.166			
	R	3200.200	0000.183		
INST	MN. ∠	1215.306			+ 28.624
B	D	1215.475		1571.384	+ 28.616
	R	4415.503	1215.489	4828.631	+ 28.631

Figure 7-22. Extract from field notebook and sketch of pointings in measuring horizontal angles, 0.002 mil theodolite.

with the direct pointing on station B (1,215.489 mils).

(7) Subtract the mean pointing on station A from the mean pointing on Station B to determine the horizontal angle from station A to station B (1,215.489—0.183=1,215.306 mils).

Note. Steps in (1) through (7) above constitute one direct and one reverse pointing on each station, which is referred to as one position.

b. When it is necessary to measure the angle to more than one station, a pointing is made on the initial station with the telescope in the direct position and then on each station around the horizon in a clockwise direction. After a reading is obtained on the last station with the telescope direct, a telescope is reversed and a pointing is made on each station in a counter-clockwise direction, ending with the initial station. One set of direct and reverse pointings on all of the observed stations constitutes one position.

c. The direct and reverse pointing on each station should differ by 3,200 mils (or 180°), plus or minus the amount of horizontal spread (twice the error in horizontal collimation) in the instrument. No value can be specified as the maximum allowable spread for an instrument; however, it should be small (0.150 mil or less) for convenience in meaning the pointings. The amount of the spread should be constant; otherwise, there are inconsistencies in operating the instrument. If the mean spread of an instrument exceeds 0.150 mil (or 30″), it should be adjusted at the first opportunity.

d. In field artillery survey, one position is normally observed for traverse. However, if the primary requirement of a traverse is to establish direction (FA missile battalion), the two positions are observed.

e. When it is necessary, as in fourth-order triangulation, to measure two positions, the second position is measured in the same manner as the first position, except that the second position normally is measured with the telescope in the reverse position for the initial pointing on each station. The initial circle settings should be as follows: first position, 0.150 (± 0.100) mils (or 00° 00′ 3″ ± 2″) second position (reverse), 4,800.150 (±0.100) mils (or 270° 00′ 30″ ± 20″).

f. The angle between two observed stations is determined by measuring and meaning the horizontal circle reading to each station and computing the difference between the mean circle readings. When two positions are taken, the value of the angle is determined by taking the mean of the values of the angle as determined from each of two positions. Figure 7–23 illustrates the method of recording horizontal circle readings and determining the horizontal angles between three stations, with two positions observed. This is not an extraction from a field notebook but is merely an example of the method to be used when recording multiple angles. Multiple angles should be measured whenever possible in order to conserve time.

g. When two positions are observed, if the two observed values for any angle differ by more than .05 mil (10″), these observed values should be rejected. If the observed values are rejected, the angle(s) must be remeasured, using approximately the same initial circle setting that was used to obtain the rejected value(s). Refer to paragraph 2–24 for the rejection limit for two positions for Pershing missile battalion or battery survey.

7–46. Repair of the Theodolite

Adjustment (except as explained in paragraphs 7–47 through 7–53) and repair of the 0.002 mil theodolite must be performed by qualified instrument repair personnel. Theodolites in need of adjustment or repair should be turned in to the engineer unit responsible for providing maintenance service. TM 5–6675–296–35 outlines the categories of maintenance.

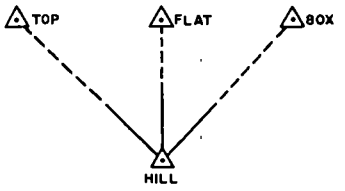
7–47. Adjustment of the Theodolite

a. The 0.002 mil theodolite must be kept in correct adjustment if accurate results are to be obtained. There are five tests and adjustments of the theodolite that should be made periodically. These tests should be performed in the sequence in which they are discussed in paragraphs 7–47 through 7–53. When a test indicates that an adjustment is necessary, this adjustment should be made and the instrument tested for accuracy before the next test is performed.

b. The five tests and adjustments of the theodolite are made with the instrument mounted on its tripod and accurately leveled. For these tests and adjustments, the instrument should be set up in the shade on firm ground with the head of the tripod as nearly level as possible. The theodolite should also be protected from the wind.

7–48. Plate Level Adjustment

a. Purpose. The purpose of the plate level ad-



STATION	T	HORIZONTAL ∠ MILS	MEAN	VERTICAL READING	VERTICAL ∠ MILS
TOP	0	0000.112			
	R	3200.134	0000.123		
HILL	MN. ∠	(814.236)			(− 10.320)
FLAT	0	0814.338		1810.314	− 10.314
	R	4014.380	0814.359	4789.673	− 10.327
HILL	MN. ∠	(896.869)			(+ 31.051)
80X	0	1711.010		1568.940	+ 31.060
	R	4911.046	1711.028	4831.042	+ 31.042

REMARKS
FIRST POSITION

STATION	T	HORIZONTAL ∠ MILS	MEAN	MEAN HORIZONTAL	
TOP	R	4800.176		814.236	ANGLE FROM FIRST POSITION
	0	1600.166	4800.171	814.202	ANGLE FROM SECOND POS.
HILL	MN. ∠	(814.202)		(814.219)	MN. ANGLE AT HILL FROM TOP TO FLAT
FLAT	R	5614.389		896.869	ANGLE FROM FIRST POSITION
	0	2414.357	5614.373	898.627	ANGLE FROM SECOND POS.
HILL	MN. ∠	(896.827)		(896.648)	MN. ANGLE AT HILL FROM FLAT TO 80X
80X	R	0111.016			
	0	3310.984	0111.000		

REMARKS
SECOND POSITION

Figure 7-23. Recording measurements of two angles, two positions with the 0.002 theodolite.

justment is to make the vertical axis of the theodolite truly vertical when the bubble of the plate level is centered in its vial (fig 7-13).

b. Test. To test the adjustment of the plate level, place the axis of the plate level parallel to two of the three leveling screws. With these two leveling screws, center the bubble of the plate level. Rotate the instrument 1,600 mils and again center the bubble, using the third leveling screw. Repeat these steps until the bubble remains centered in both positions. Carefully center the bubble in the first position and then rotate the instrument 3,200 mils. If the bubble does not remain centered, adjustment is required; the discrepancy noted in the position of the bubble is the apparent error, or twice the actual error, of the plate level.

c. Adjustment. To adjust the plate level, remove one-half of the apparent error (the actual error) by turning the capstan adjusting screw located below the collimation level illuminator. The adjusting pin is used to turn the capstan adjusting screw. Repeat the test to detect any error remaining in the adjustment of the plate level and adjust, if necessary.

7-49. Optical Plumb Adjustment

a. Purpose. The purpose of the optical plumb

adjustment is to aline and center the optical plumb in the vertical axis of rotation of the theodolite when the theodolite is properly leveled and the station mark is centered in the reticle of the optical plumb (fig 7–14).

b. Test. To test the optical plumb, suspend the plumb bob from the leveled instrument and mark a point on the ground exactly under the point of the plumb bob. Remove the plumb bob from the instrument and check to insure that the instrument is accurately leveled (i.e., the vertical axis is truly vertical). Look into the eyepiece of the optical plumb. If it is correctly adjusted, the mark on the ground will be centered in the reticle.

c. Adjustment. If the point on the ground is not centered in the optical plumb reticle, center the point by means of the three capstan adjusting screws located near the optical plumb eyepiece. Two of these adjusting screws are located on opposite sides of the eyepiece, and the third adjusting screw is located below the eyepiece opposite a spring-loaded plunger. The bottom adjusting screw is locked in place by a capstan retaining nut, which is located immediately above the head of the adjusting screw. With an adjusting pin, loosen the retaining nut and raise or lower the reticle by turning the bottom adjusting screw to move the reticle image along the axis of the optical plumb in the same direction that the screw travels. The two side adjusting screws are used to move the image of the reticle in the opposite direction from their travel. If it is necessary to use these screws, they should be rotated an equal amount in opposite directions. It is usually necessary to loosen the screw below the eyepiece slightly to adjust the screws on the side and vice versa. To make the adjustment, loosen one of the two opposed screws and the retaining nut slightly. The spring-opposed adjusting screw should be used for necessary adjustments, and the opposed adjusting screws should be used to complete these adjustments. When the adjustment is complete, the two opposed adjusting screws must be fairly tight. Lock the bottom adjusting screw in place by tightening the retaining nut.

7–50. Verticality Adjustment

a. Purpose. The purpose of the verticality adjustment is to make the vertical crossline of the reticle lie in a plane perpendicular to the horizontal axis of the telescope.

b. Test. To test the verticality of the vertical crossline, select a well-defined distant point as near as possible to the horizontal plane of the instrument and center the vertical crossline on the selected point. With the vertical tangent screw, elevate and depress the telescope. If the vertical crossline continuously bisects the point the adjustment is correct.

c. Adjustment. There are three adjusting screws on the telescope—a horizontal screw on the left side and two slant screws on the right side. If the vertical line does not continuously bisect the sighted point, turn the two slant screws an equal amount in opposite directions (by slightly loosening one screw and tightening the other) to rotate the reticle until the verticle crossline does bisect the point throughout the elevation and depression of the telescope. Some of the later models of the 0.002-mil theodolite require no verticality adjustment.

7–51. Horizontal Collimation Adjustment

a. Purpose. The purpose of the horizontal collimation adjustment is to make the line of sight perpendicular to the horizontal axis of the telescope (fig 7–15).

b. Test. To test the horizontal collimation select a well-defined point at least 100 meters from the instrument and at approximately the same relative height. With the telescope in the direct position, center the vertical crossline on the selected point. Set the horizontal circle to any reading less than 3,200 mils, close the cover on the circle-setting knob, and record the reading. Plunge the telescope to the reverse position and take a second reading on the same point. The instrument operator should repeat both readings to insure that no error was made in reading the instrument. These two readings should differ by 3,200 mils. Assuming no error in the pointings or readings, any discrepancy between the actual difference in the two readings and 3,200 mils is the apparent error, or twice the horizontal collimation error. If this discrepancy exceeds plus or minus 0.150 mil (30″), the horizontal collimation adjustment should be performed.

c. Adjustment. For the purpose of illustration, assume that the horizontal circle reading in the direct position is 0000.200 mil and in the reverse position is 3,200.800 mils. With the telescope in the direction position, use the coincidence knob to set the mean value (0.500) on the micrometer scale. Using the horizontal tangent screw, bring

the main scale into coincidence with a value of 0 mil on the scale. In doing this, the vertical crossline is moved off the point by the amount of the horizontal collimation error. The vertical crossline is then alined on the selected point by lateral movement of the reticle within the telescope. To move the reticle, loosen (tighten) the two adjusting screws in the slant position on the right side of the telescope equally, and tighten (loosen) the single adjusting screw on the left side of the telescope. For moving the reticle, the adjusting screw(s) should be loosened before the screw(s) on the opposite side of the telescope is tightened. Repeat the test and adjustment procedure until the difference between the direct and reverse points is less than 0.050 mil (10″).

Note. Newer models of the 0.002 mil theodolite have two pull-action capstan adjusting screws arranged horizontally and on opposite sides of the telescope near the eyepiece. They are adjusted as is the 0.2 mil theodolite and, like the 0.2 mil theodolite, this model does not require a verticality adjustment. When this adjustment is completed, repeat the verticality test to insure that the vertical crossline is still perpendicular to the horizontal axis of the telescope. This adjustment can also be made with the telescope in the reverse position, using the mean value for the reverse pointing i.e., 3,200.500.

7–52. Vertical Collimation Adjustment

a. Purpose. The purpose of the vertical collimation adjustment is to make the line of sight horizontal when the vertical circle reads 1,600 mils with the telescope in the direct position (4,800 mils with the telescope in the reverse position) and the ends of the collimation level bubble in alinement (fig 7–16).

b. Test. To test the vertical collimation, select a well-defined point at least 100 meters from the instrument. With the telescope in the direct positon, take a vertical circle reading on the point, making sure that the collimation level bubble is precisely alined before, and checked after, each vertical circle reading. Repeat these two measurements to insure that no error was made. The sum of the two readings should equal 6,400 mils. Assuming no error in the pointings or readings, any difference between the sum of the two readings and 6,400 mils is the apparent (index) error, or twice the collimation level error. If the difference exceeds plus or minus 0.150 mil (30″), the vertical collimation level should be adjusted.

c. Adjustment. To adjust the vertical level, compute the correct vertical circle reading by applying one-half of the index error of the vertical circle to the direct reading. If the sum of the two readings is greater than 6,400 mils, subtract one-half the index error from the direct reading; if the sum is less than 6,400 mils, add one-half the index error to the direct reading. Place the instrument in the direct position and accurately sight on the point. Using the coincidence knob, set the fractional part of the correct vertical circle reading on the micrometer scale, and then obtain coincidence on the main scale at the correct vertical circle reading by using the collimation level tangent screw. With the telescope sighted on the point and the correct reading on the vertical circle, the ends of the collimation level bubble will not be alined. Aline the images of the ends of the collimation level bubble by using the two capstan adjusting screws located immediately below the collimation level. When adjusting the bubble, rotate both screws the same amount in opposite directions. After making the adjustment, tighten the screws by rotating the screws slightly in opposite directions, being careful not to change the alinement of the ends of the bubble. Repeat the test and adjustment procedure until the collimation level error is less than 0.050 mil (10″).

Example:

Vertical circle reading for direct pointing	1,544.400
Vertical circle reading for reverse pointings	4,856.098
Sum	6,400.498

Apparent (index) error = 6,400.498 — 6,400 = 0.498 mil
Collimation error = 0.498 ÷ 2 = 0.249 mil
Correct vertical circle reading (direct) = 1,544.400 — 0.249 = 1,544.151

With the telescope in the direct position, accurately sight on the point. Set the fractional portion of the correct scale reading on the micrometer scale by using the coincidence knob, and then obtain coincidence on the main scale at the correct vertical circle reading (1,544.151) by using the collimation level tangent screw. Bring the split bubble into coincidence by turning its adjusting screws.

Note. This adjustment can also be made with the telescope in the reverse position, using the mean value for the reverse pointing; i.e., 4,856.098 — 0.249 = 4,855.849 mils.

7–53. Other Adjustments

Other adjustments to the 0.002 mil theodolite that may be required periodically are as follows:

a. Leveling Screws. The three leveling screws must turn smoothly and with moderate ease and without any shake or backlash. To tighten or loosen the movement of the leveling screw, use the

capstan adjusting screw located immediately above each leveling screw.

b. Tangent Screws. The tangent screws must turn easily and smoothly, without backlash, throughout their travel. A capstan adjusting ring is located immediately behind each tangent screw. To adjust the tangent screws, rotate the adjusting ring with an adjusting pin.

c. Circle-Setting Knob. To adjust the circle-setting knob, turn the knob until three screws can be seen through the three holes in the face of the knob. Carefully loosen these screws enough to press the knob upward or downward to loosen or tighten the movement.

d. Tripod. There should be no play at the junction of the wood and metal parts of the tripod. If play exists, tighten the hexagon nuts on the foot plates and on the extensions of the tripod head. The legs, when released from the horizontal position, should fall to an angle of about 45° and remain there. Check the movement of the legs and, if necessary, tighten the clamping screws under the head of the tripod.

CHAPTER 8
FIELD NOTES

Section I. GENERAL

8-1. Field Records

The field notes of any survey are the only original record of the survey that the survey party has, once they leave the field. Therefore, the field notebook must contain a *complete* record of all measurements made or determined during the progress of the survey, with complete sketches, descriptions, and remarks made when necessary to clarify the notes. The best survey fieldwork is of no value to the using unit if the notes are not accurate, legible, and complete in every detail.

8-2. Field Notebook

The field notebook (DA Form 5-72, Level, Transit, and General Survey Record Book) is a hard back, permanently bound book for recording all survey data as it is determined in the field. Attached to the flyleaf inside the front of the book are instructions to the finder for the book's return in the event it is lost. The flyleaf contains space for the identification of the notebook (fig 8-1).

Each set of two adjoining pages comprises one numbered page. The page number appears in the upper right corner. The first two *numbered* pages should be reserved for the index of the contents of the notebook and is maintained as field data entries are made (fig 8-2). The index should be kept current at all times.

8-3. Forms of Recording

a. Field note recording consists of a combination of tabulation of data, sketches, and descriptions so that the total record of any survey in the field notebook provides a clear and concise picture of the survey performed. This information should include descriptions of the starting and closing stations, a description of any principal station established, the area or locality in which the work is performed, the purpose of the survey, and general remarks on weather, terrain, or other conditions that may be factors in evaluating the results. The information in the field notes should be complete to the extent that anyone not familiar with that particular survey operation can take the notebook, return to the locality, and recover or reconstruct any portion of the fieldwork.

b. The recording of data in the field notebook is the tabulation of the field data in columns according to a prescribed plan. Sufficient spaces are also provided to permit entry of mean values as they are determined by the recorder.

c. Sketches should be made when needed. All sketches should be drawn to an approximate scale and a grid north line should be shown. Important details of the sketch may be exaggerated for clarity. A sketch showing the general survey plan should provide sufficient information to enable recovery or reconstruction of the fieldwork. Sketches should show distances from any reference mark (minimum of two) to any principal station which might be buried underground. Reference marks should be permanent in nature. If none are available, semipermanent marks should be emplaced by the survey party. Sketches are also used when necessary to indicate heights of survey signals and other points when observing vertical angles to other than instrument height. A small protractor, which can also be used as a straightedge, should be used as an aid in making the sketch. The sketch should be legible and should be drawn large enough to assure a thorough understanding. Each station shown on the sketch should be designated.

d. Descriptions should be used to supplement the information shown in the sketch. Remarks may be made to clarify measurements, weather, terrain and observing conditions and should contain any other factors that might be of any value in the evaluation of the survey. Approved abbreviations and conventional symbols should be used on sketches and in descriptions.

8-4. Recording

a. Each numbered page of the field notebook (fig

DEPARTMENT OF THE ARMY

CORPS OF ENGINEERS

LEVEL, TRANSIT AND GENERAL SURVEY

RECORD BOOK

1ST HOW BN 1ST ARTY

LOCALITY

ADVANCED UNIT TRAINING

PROJECT

BOOK 1 OF 3

0.2 MIL THEODOLITE NR 1380

INSTRUMENT

SFC T.L. BROWN

CHIEF OF PARTY

Figure 8–1. Example of data placed on flyleaf of field notebook.

8–3) provides space for recording data and information pertinent to the surgey. The type of survey (traverse, resection, etc.), and the date are entered at the top of the left half of the page. Weather conditions, the type and serial number of the instrument, and the names of the party personnel are entered across the top of the right half of the page. The left half of the page is used for recording readings and determining angles, for recording distances (if electronically measured it should be so noted) and for designating the survey stations involved. The right half of the page is used for remarks, sketches and descriptions. The chief of party will initial each numbered page after checking the data entered on that page prior to leaving the field. (If an incorrect angle or distance is discovered, it can be remeasured prior to leaving the work site.)

b. All entries in the field notebook should be printed in a neat and legible manner with a sharpened pencil, soft enough to be readily seen but hard enough to be smear proof (3H or 4H generally accepted). Entries should *never* be made in ink. The recorder accompanies the instrument operator and records the data in the field notebook as it is announced to him; he then reads it back to the instrument operator to insure the correctness of his entry. Field data are entered directly in the field notebook and not on scraps of paper for later transfer. As the field data entries are made, the recorder computes and records mean values and, for ease of identification, encircles the data that is to be furnished to the computers as they request it. The recorder will immediately notify the instrument operator of any incorrect angle before the instrument is moved from the station. Station

DESIGNATION INDEX DATE _____ 19 69

PAGE	DATE	TITLE			
1	——	INDEX			
2	5 JAN	DECLINATION			
3	7 JAN	TARGET AREA SURVEY			
4	8 JAN	TARGET AREA SURVEY			
5	10 JAN	POSITION AREA SURVEY			
6	15 JAN	CONNECTION SURVEY			
7	18 JAN	TRAVERSE (REC. VERT. 4)			
8	25 JAN	TRIANGULATION			
9	1 FEB	SUN OBSER- ALTITUDE			
10	11 FEB	STAR OBSER-HOUR ANGLE			
11	12 FEB	TRAVERSE			
12	13 FEB	DME TRAVERSE			
13	15 FEB	TRILATERATION			
14	18 FEB	TRIANGULATION			
15	18 FEB	TRIANGULATION (CONT)			
16	21 FEB	SUN OBSER- HOUR ANGLE			
17	25 FEB	E-W STAR OBSER- ALTITUDE			
18	28 FEB	SIMO. OBSER - MASTER			
19	28 FEB	SIMO. OBSER - FLANK			
20	1 MAR	AZIMUTH GYRO.			
21	12 MAR	ALTIMETRY - LEAPFROG			
22	12 MAR	ALTIMETRY (CONT.)			
23	12 MAR	ALTIMETRY (CONT.)			

PAGE	DATE	TITLE			

Figure 8–2. Example of the index of the field notebook.

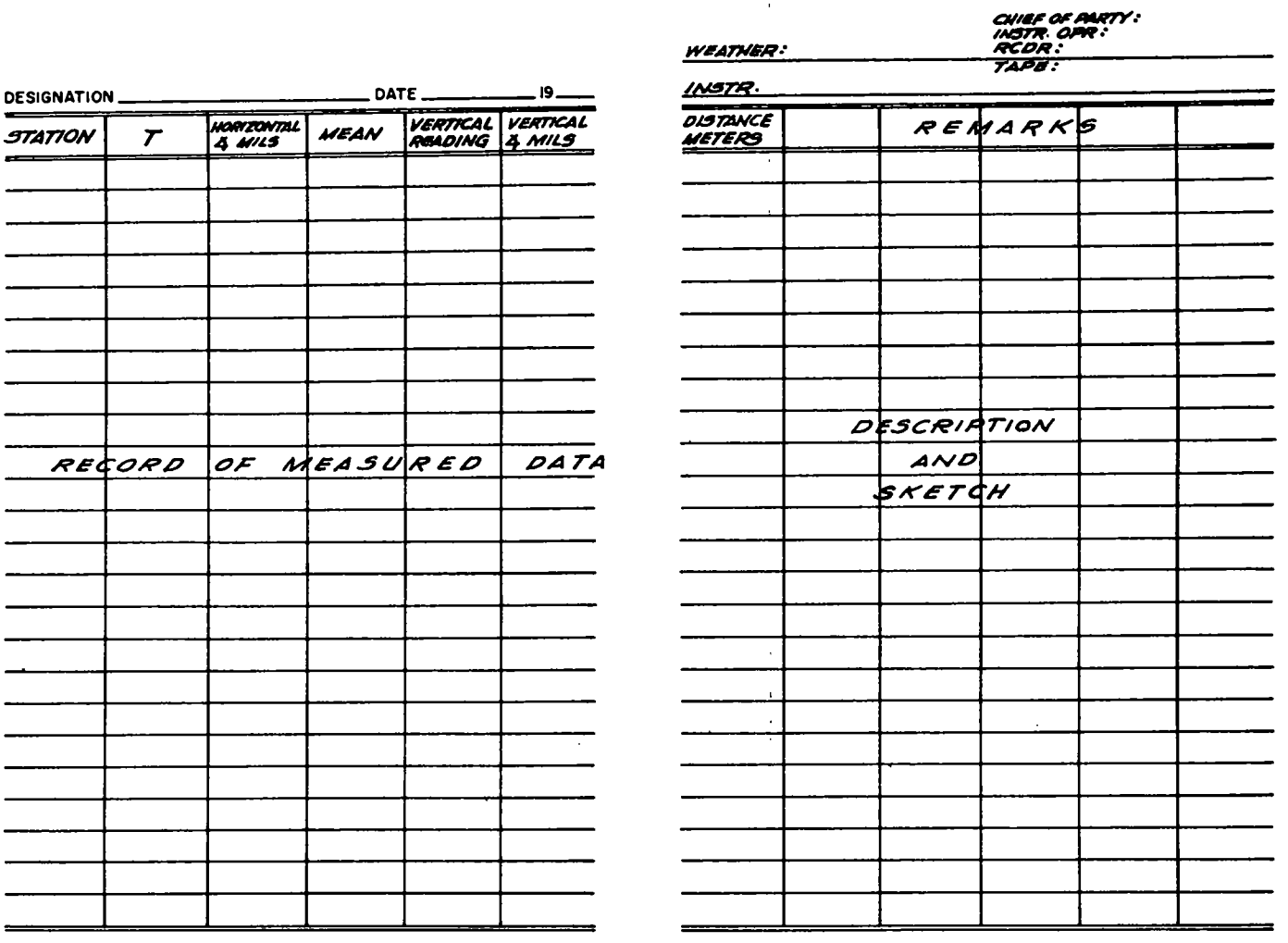


Figure 8–3. Column headings, typical page of field notebook.

descriptions, sketches, and remarks are entered in the notebook before moving to the next station and must be complete enough to permit relocation from this source alone. Only the data for that specific survey will be recorded on the page. Data pertaining to surveys other than the one in progress will be recorded on other pages.

c. Erasures are not permitted in the field notebook. When incorrect entries are made, they are corrected by drawing a single line through the incorrect data and entering the correct data directly above the incorrect data. When a page is filled with data or sketches and remarks that will not be used because of change in plans, etc., the page is crossed out by drawing diagonal lines between opposite corners of the page and printing the word VOID in large letters across the page.

Section II. TYPES OF FIELD NOTES

8–5. Traverse Field Notes

a. Figure 8–4 is an example of field notes kept by a recorder for an aiming circle traverse (1:500).

b. Figure 8–5 is an example of field notes kept by a recorder for a 1:1,000 traverse using a 0.2 mil theodolite.

c. Figure 8–6 is an example of field notes kept by a recorder for a 1:3000 traverse using a 0.002 mil theodolite.

d. Figure 8–7 is an example of field notes kept by a recorder for a DME traverse (1:3000).

DESIGNATION RADAR, 2d BN, 18th ARTY DATE 3 MARCH 19 69

STATION	R	HORIZONTAL ∠ MILS	VERTICAL ∠ MILS	CORRECTED VERTICAL	DISTANCE METERS
AZ MK	1	1675.0	+5.0	+8.0	
BN SCP	2	3350.5	+5.5	+8.5	
TS 1	MN ∠	(1675.2)		(+8.2)	(158.52)
BN SCP	1	4703.0	-9.0	-6.0	
TS 1	2	3006.5	-9.5	-6.5	
RADAR	MN ∠	(4703.2)		(-6.2)	(97.40)
TS 1	1	4791.0	+1.5	+4.5	
RADAR	2	3182.0	+2.0	+5.0	
TS 2	MN ∠	(4791.0)		(+4.8)	(115.82)
RADAR	1	4435.5	-8.5	-5.5	
TS 2	2	2471.5	-9.5	-6.5	
BN SCP	MN ∠	(4435.8)		(-6.0)	(118.78)
TS 2	1	2805.0			
BN SCP	2	5610.5			
AZ MK	MN ∠	(2805.2)			

WEATHER: CLEAR & HOT
CHIEF OF PARTY: SSG. GREEN
INSTR OPR: SP4 REESE
RECORDER: SP5 WALL
INSTR NO: M-2 AC #1541
TAPE: PFC THOMAS & BUELL

REMARKS

VERTICAL ANGLE CORRECTION = +3.0 MILS
BN SCP IS LOCATED 14 METERS N. OF ℄ OF BLUE BEAVER RD, 68 METERS W. OF SW COR OF LITTLE AVE SCHOOL. BN SCP IS TACK IN CENTER OF 2" x 2" WOODEN HUB DRIVEN FLUSH WITH GROUND. AZ. MK IS FLAG POLE LOCATED APPROX. 450 METERS SW OF BN SCP.

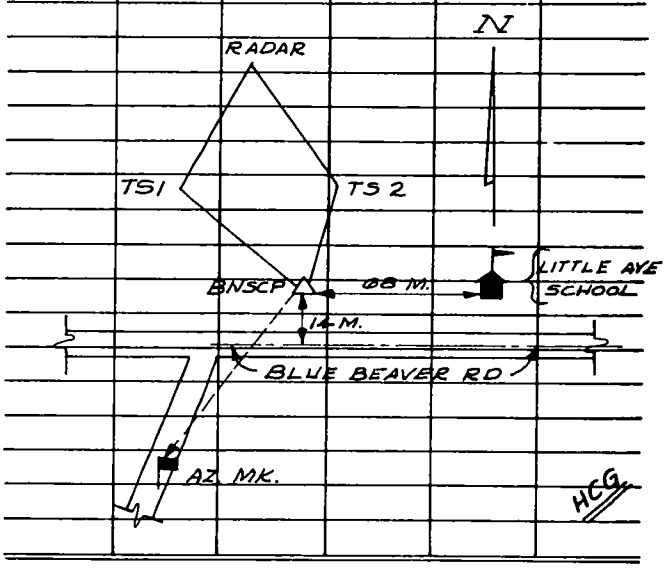


Figure 8–4. Traverse (1:500) notes, aiming circle.

8–6. Triangulation Notes

a. Figures 8–8 and 8–9 are examples of field notes kept by a recorder for a 1:3000 triangulation problem.

b. Figure 8–10 is an example of field notes kept by a recorder for a 1:000 triangulation problem.

c. Figure 8–11 is an example of field notes kept by an 02 recorder for an intersection problem from a target area base.

d. Figure 8–12 is an example of field notes kept by a recorder for a trilateration problem.

8–7. Astronomical Observation Notes

a. Figure 8–13 is an example of field notes kept by a recorder for an astonomic observation on an East-West Star (HAMAL), Altitude Method using a 0.002 mil theodolite.

b. Figure 8–14 is an example of field notes kept by a recorder for an astronomic observation on the sum (altitude method) using a 0.2 mil theodolite.

c. Figure 8–15 is an example of field notes kept by a recorder for an astronomic observation (hour-angle method) on Polaris using a 0.2 mil theodolite.

d. Figure 8–16 is an example of field notes kept by a recorder for an azimuth determination using a gyro azimuth surveying instrument.

DESIGNATION POSITION AREA SURVEY DATE 10 JAN 19 69

STATION	T	HORIZONTAL ∠ MILS	MEAN	VERTICAL READING	VERTICAL ∠ MILS
AZ MK	D	0001.0			
	R	3200.9	0001.0		
BNSCP	MN ∠	0942.2			+11.5
05"B"	D	0943.1		1588.5	+11.5
	R	4143.2	0943.2	4811.5	+11.5
BNSCP	D	0001.0			
	R	3201.0	0001.0		
05"B"	MN ∠	1585.1			-11.5
B CEN	D	1586.1		1611.4	-11.4
	R	4786.1	1586.1	4788.4	-11.6
05"B"	MN ∠	1820.5			+14.2
MAC	D	3406.5		1585.9	+14.1
	R	0206.7	3406.6	4814.3	+14.3
05"B"	D	0001.0			
	R	3208.8	0000.9		
MAC	MN ∠	1492.3			
AZ MK	D	1493.1			
	R	4693.2	1493.2		

CHIEF OF PARTY: 330 HENDRIX
INST OPR: SP4 VOGEL
RCDR: SP4 REEVES
TAPE: PFC LAWSON
SP4 MERLINO

WEATHER: OVERCAST-COLD
INST: 0.2 mil. NO. 1570

DISTANCE METERS	REMARKS
	BNSCP IS 3.2 MILES W. OF BM 189
	AND 21 METERS N OF ℄ WEST RD. BNSCP
485.73	IS TACK IN 2"x 2" WOODEN HUB FLUSH
	WITH GROUND, MARKED WITH WITNESS
	STAKE. AZ. MK. IS STA ZEB ON ZEB
	RIDGE, MARKED WITH A QUAD MARKER.
	ANGLE BNSCP – 05"B" – STA MAC = 3405.6 mil.
89.34	N
365.01	

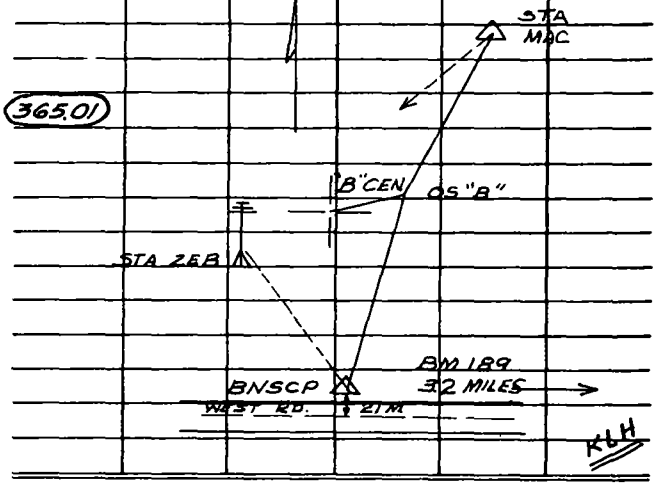


Figure 8–5. Traverse (1:1,000) notes, 0.2 mil theodolite.

e. Figures 8–17 and 8–18 are examples of field notes kept by recorders during simultaneous observations at both the Master and the Flank stations.

8–8. Miscellaneous Notes

Figure 8–19 is an example of field notes kept by a recorder during the declinating of an aiming circle.

DESIGNATION TRAVERSE DATE 15 MARCH 1969

STATION	T	HORIZONTAL ∠ MILS	MEAN	VERTICAL READING	VERTICAL ∠ MILS
KIOWA	D	0000.167			
	R	3200.182			
DODGE	MN. ∠	3195.696	0000.174		+20.371
TS-1	D	3195.883		1579.419	+20.581
	R	6395.856	3195.870	4820.561	+20.561
DODGE	D	0000.172			
	R	0000.156	0000.164		
TS-1	MN. ∠	2552.384			-18.913
TS-2	D	2552.543		1618.902	-18.902
	R	5752.554	2552.548	4781.076	-18.924

WEATHER: CLEAR-COOL
CHIEF OF PARTY: SSG DAVIS
INST OPR: SP4 BARTH
RCDR: PFC JUST
INST: .002 MIL THEOD.

DISTANCE METERS	REMARKS
	STA DODGE IS IN NORTH ARBUCKLE
	AREA, FORT SILL MILITARY RESERVA-
672.10	TION, 0.8 MILES W. OF BALD RIDGE
	CENTRAL ON HIGHEST POINT OF GRASSY
672.12	HILL. STA IS 4 METERS W. OF ℄ N-S
672.08	ROAD, 5 METERS N. OF ℄ E-W ROAD,
	MARKED BY 1" PIPE IN CONCRETE
	FLUSH WITH GROUND AND 15' WHITE
	WOODEN QUAD MARKER. AZ MK
537.92	IS QUAD MARKER ON KIOWA HILL
	2200 METERS SW OF STA DODGE.
537.88	
537.97	

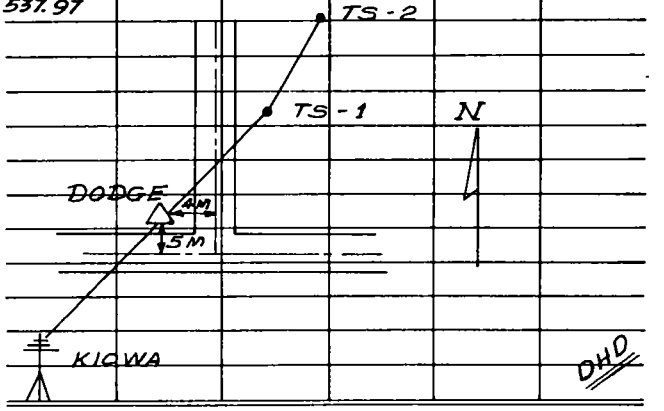


Figure 8-6. Traverse (1:3,000) notes, 0.002 mil theodolite.

DESIGNATION DME TRAVERSE DATE 16 MARCH 1969

STATION	T	HORIZONTAL ∠ MILS	MEAN	VERTICAL READING	VERTICAL ∠ MILS
AZ MK	D	0000.149			
	R	3200.194	0000.172		
ZED	MN ∠	2131.825			(-15.944)
TS-1	D	2131.996		1615.947	-15.947
	R	5331.998	2131.997	4784.059	-15.941
					(+11.639)
TS-2	D	0000.222		1588.358	+11.642
	R	3200.211	0000.216	4811.636	+11.636
TS-3	MN ∠	484.226			(+13.980)
TS-4	D	0484.444		1586.029	+13.971
	R	3684.440	0484.442	4813.989	+13.989

CHIEF OF PARTY: SSG KEEFE
WEATHER: CLEAR–COLD INSTR OPR: SP4 MANN
RECOR: SP4 JONES
INST: DME NO. 110
.002 MIL THEOD. NO. 1370.

MN. OF RECIP ∠'s	DISTANCE METERS	REMARKS
		STA ZED IS 200 METERS N. OF
		℄ CROW CANYON RD, 3.5 KM. W OF
(-15.934)	(9669.71)	INTERSECTION WITH COAL CREEK
		RD. STA IS MARKED BY BRONZE
-15.944		DISK IN CONCRETE CYLINDER.
+15.923		AZ MK IS STA ZEKE, ON SOUTH
		RIDGE, BAT CAVE MOUNTAIN,
	(13,379.38)	MARKED WITH QUAD MARKER.
(+13.990)	(8126.52)	
+13.980		
-14.000		

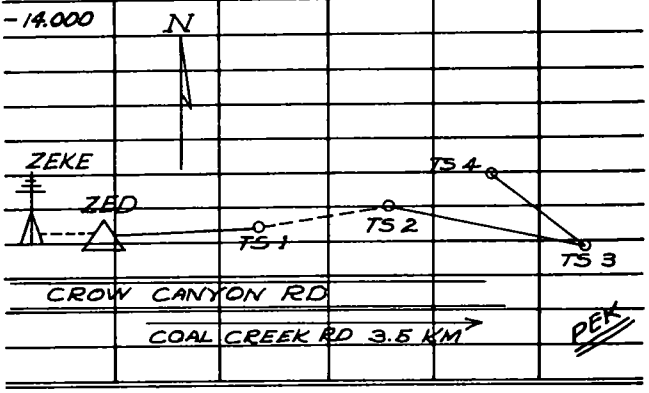


Figure 8–7. DME travese notes.

DESIGNATION TRIANGULATION DATE 20 MAR 19 69

STATION	T	HORIZONTAL ∠ MILS	MEAN	VERTICAL READING	VERTICAL ∠ MILS
MUSEUM	D	0000.104			
	R	3200.120	0000.112		
DICK	MN ∠	485.336			-20.522
TOWER	D	0485.424		1620.515	-20.515
	R	3685.471	0485.448	4779.471	-20.529
DICK	MN ∠	139.205			+ 8.799
ROSSI	D	0624.619		1591.207	+8.793
	R	3824.687	0624.653	4808.805	+8.805

CHIEF OF PARTY: SSG KEY
WEATHER: WARM–CLEAR INSTR OPR: SP4 KING
INST: .002 MIL NO. 1772 RCDR: SP4 FERN

REMARKS

FIRST POSITION OF TWO POSITIONS. AZ TO AZ MK = DICK–MUSEUM = 6049.100 MILS.
BASE LENGTH: DICK–MUSEUM = 2875.69 M.
ALL HEIGHTS ABOVE STA ELEVATION
HI = 1.5 M. ANGLE MUSEUM–DICK–ROSSI = 624.541 MILS

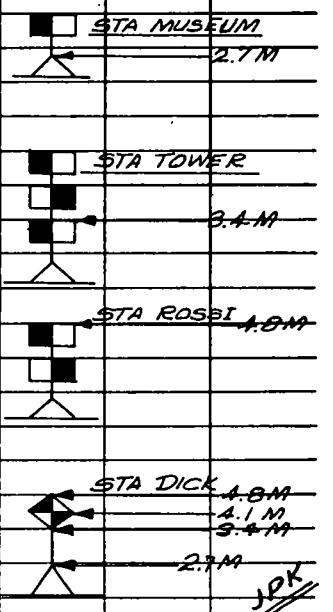


Figure 8–8. Fourth order triangulation, 1st position notes.

DESIGNATION TRIANGULATION (CONT.) DATE 20 MAR. 1969.

STATION	T	HORIZONTAL ∠ MILS	MEAN	MEAN HORIZ ∠	
MUSEUM	R	4800.138		0485.336	1ST POS ∠
	D	1600.107	4800.122	0485.356	2ND POS ∠
DICK	MN ∠	(485.356)		(485.346)	MN ∠
TOWER	R	5285.488		0139.205	1ST POS ∠
	D	2085.467	5285.478	0139.236	2ND POS ∠
DICK	MN ∠	(139.236)		(139.220)	MN ∠
ROSSI	R	5424.701			
	D	2224.727	5424.714		

REMARKS

SECOND POSITION

STA DICK IS LOCATED ON NORTH APACHE HILL 14 METERS W. OF CONCRETE BUNKER, STA IS A 105 MM SHELL CASING SET IN CONCRETE FLUSH WITH GROUND. A QUAD MARKER IS ERECTED OVER STATION. ANGLE MUSEUM-DICK-ROSSI = 624.592 MILS (MEAN ANGLE = 624.566 MILS) STAS MUSEUM AND ROSSI IN BOOK 2 OF 3, PAGES 13 AND 14, 18 MAR. 69. STA TOWER IN BOOK 3 OF 3, PAGE 10, 18 MAR 69.

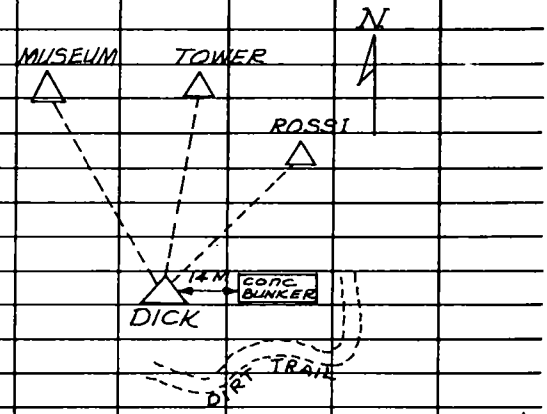


Figure 8–9. Fourth order triangulation cont'd, 2d position notes.

DESIGNATION TRIANGULATION DATE 22 MAR 1969.

STATION	T	HORIZONTAL ∠ MILS	MEAN	VERTICAL READING	VERTICAL ∠ MILS
MB 4	D	0001.0			
	R	3200.9	0001.0		
BUCK	MN ∠	1634.0			+1.8
MONSTER	D	1635.0		1598.2	+1.8
	R	4834.9	1635.0	4801.8	+1.8
BUCK	MN ∠	1723.2			-1.1
DODGE	D	3358.3		1601.1	-1.1
	R	0158.2	3358.2	4798.9	-1.1

WEATHER: CLOUDY- COLD
INST: 0.2 MIL NO. 1969

CHIEF OF PARTY: 33G COX
INST OPR: SP4 BARTH
RCDR: PFC CROSSLEY

REMARKS

STA BUCK IS 5.5 MILES N. OF COURT HOUSE IN LAWTON, OKLA., ON HWY. 277, 75 METERS E. OF ℄ OF HWY.; 90 METERS S. OF WHITE FARM HOUSE. STA. IS 1/4" STEEL ROD SET IN 6"x6" CONCRETE BLOCK 4" ABOVE GROUND. BASE OF TRIANGULATION SCHEME IS "BUCK-DODGE." COMPUTED LENGTH OF BASE = 2489.78 METERS. STA MONSTER IN BOOK 2 OF 3, PAGE 8. STA DODGE IN BOOK 3 OF 3, PAGE 7. ANGLE MB 4-BUCK-DODGE = 3357.2 MILS

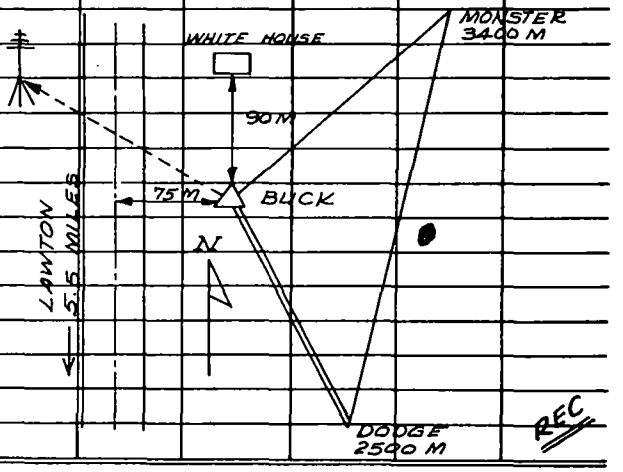


Figure 8-10. Fifth order triangulation notes.

TARGET AREA SURVEY

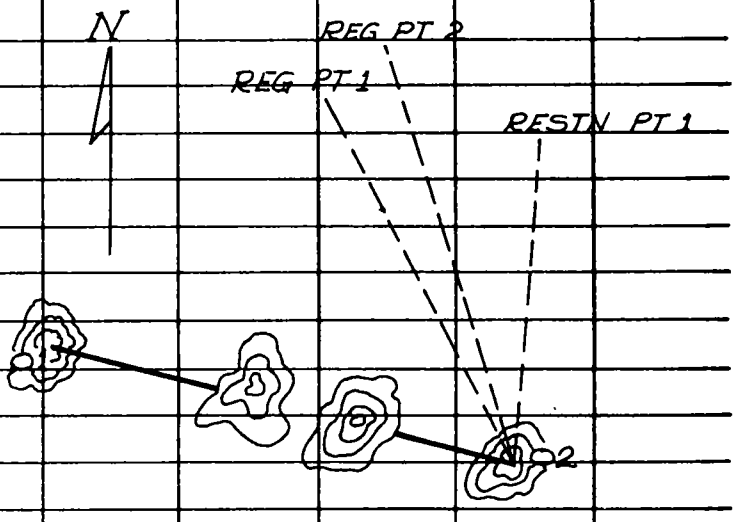
DESIGNATION OPS NON-INTERVISIBLE DATE 8 JAN 19 69

STATION	R	HORIZONTAL ∠ MILS			
AZ MK	1	2807.5			
02	2	5615.5			
RP 1	MN. ∠	2807.8			
AZ MK	1	3062.0			
02	2	6124.0			
RP 2	MN ∠	3062.0			
AZ MK	1	3426.5			
02	2	0453.5			
RESTN PT 1	MN ∠	3426.8			

WEATHER: CLEAR-WINDY-COOL
CHIEF OF PARTY: SSG BROWN
INST. OPR: SP4 BRYON
INST: M2 (AC) NO. 1798
RCDR: SP4 DAVIS

REMARKS

REG PT 1 IS CONCRETE BUNKER. REG PT 2 IS PROMINENT BOULDER ON CREST OF RIDGE. RESTN. PT 1 IS HOUSE ON RIGHT EDGE OF TARGET AREA. OT ∠'S IN BOOK 2 OF 3, PAGE 2.



GDB

Figure 8–11. Recorder's notes made at 02, intersection.

DESIGNATION TRILATERATION DATE 17 MAR. 19 69.

STATION (INST. NO.)	HEIGHT METERS	SLOPE DISTANCE	MEAN SLOPE DIS.	SEA-LEVEL DIST.
SACK (609)	378.6			
		2191.24		
		2191.26	2191.25	(2190.14)
RAG (610)	443.7			
		1197.66		
		1197.64	1197.65	(1197.22)
QUARRY (611)	473.6			
		3277.41		
		3277.43	3277.42	(3275.84)
SACK (609)	378.6			
RAG (610)	443.7			
		3673.35		
		3673.33	3673.34	(3670.63)
PIN (609)	411.3			
		2574.41		
		2574.41	2574.41	(2573.49)
QUARRY (611)	473.6			
PIN (609)	411.3			
		2178.19		
		2178.21	2178.20	(2177.82)
SACK (610)	378.6			

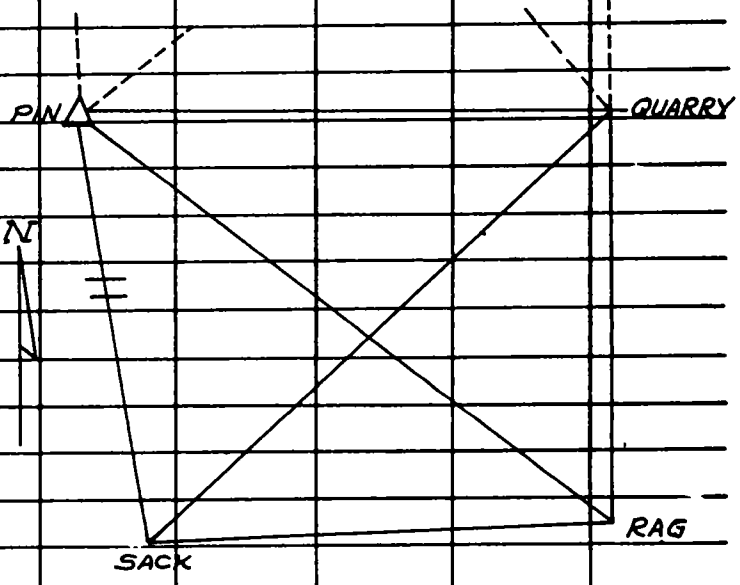
WEATHER WARM-WINDY

CHIEF OF PARTY: SSG. GOMEZ
RCDR: SP4 KING

INST: DME (MC8) INST OPR: #609 PFC GREEN #610 SP4 MAY #611 SP4 SMITH

REMARKS

STA "PIN" IS .30 CAL CARTRIDGE SET IN CONCRETE TRIANGLE FLUSH WITH GROUND. STA "SACK" IS LOCATED AT COORD. 569258.14 -3870369.25 ON LONE PEAK. AZ SACK TO PIN = 6253.941 MILS. HEIGHT OF STATIONS DETERMINED BY ALTIMETRY.



RLG

Figure 8–12. Trilateration notes.

EAST-WEST STAR OBSERVATION

DESIGNATION ALTITUDE METHOD DATE 25 MAR. 1969

CHIEF OF PARTY: SGT. LUKE
WEATHER: CLEAR-COOL INSTR. OPR: SP4 SHERIDAN
RCDR: SP4 GEROLD
INST: .002 MIL NO 1112

STATION	T	h	m	s	HORIZONTAL ∠ MILS	MEAN
TS 16	D				0000.164	
	R				3200.177	0000.170
TS 17	MN ∠	20	33	50	1645.718	
HAMAL	D	20	32	45	1643.562	
	R	20	34	56	4848.214	1645.888
TS 16	D				0000.158	
	R				3200.143	0000.150
TS 17	MN ∠	20	41	42	1666.733	
HAMAL	D	20	40	18	1663.825	
	R	20	43	05	4869.941	1666.883
TS 16	D				0000.162	
	R				3200.148	0000.155
TS 17	MN ∠	20	50	47	1680.899	
HAMAL	D	20	49	43	1678.432	
	R	20	51	51	4883.675	1681.054

VERTICAL READING	VERTICAL ∠ MILS	REMARKS
		LATITUDE: 34° 41' 42" N
		LONGITUDE: 98° 36' 42" W
	+410.127	WATCH: SLOW; CORR +12s
		TEMP: 45°F
1193.421	+406.579	TS 17 IS WOODEN HUB
5213.675	+413.675	NEXT TO LARGE BOULDER
		APPROX. TO METERS N. AND
		50 METERS W. OF KETCH
		RANCH HOUSE.
	+439.784	
1164.731	+435.269	
5244.298	+444.298	
	+471.865	
1131.383	+468.617	
5275.113	+475.113	

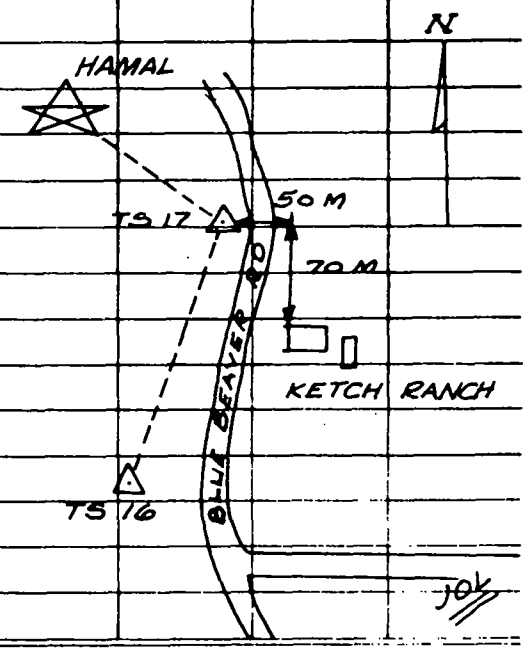


Figure 8-13. Altitude method notes, star HAMAL, 0.002 mil theodolite.

SUN OBSERVATION

DESIGNATION ALTITUDE METHOD DATE 1 APRIL 1969

CHIEF OF PARTY: SSG BIK
WEATHER: CLEAR - COOL — INSTR OPR: SP4 JUST
INSTR: 0.2 MIL NO 5459 — RCDR: SP4 BROWN

STATION	T	TIME h	m	s	HORIZONTAL ∠ MILS	MEAN
WT	D				0001.0	
	R				3201.0	0001.0
SD 260	MN ∠	08	30	30	3823.8	
SUN	D	08	28	28	3821.1	
	R	08	32	32	0628.4	3824.8
WT	D				0001.0	
	R				3200.9	0001.0
SD 260	MN ∠	08	36	21	3846.4	
SUN	D	08	34	24	3845.7	
	R	08	38	18	0649.2	3847.4
WT	D				0001.0	
	R				3201.0	0001.0
SD 260	MN ∠	08	50	46	3881.2	
SUN	D	08	48	51	3879.5	
	R	08	52	41	0684.8	3882.2

VERTICAL READING	VERTICAL ∠ MILS	REMARKS
		LATITUDE 34° 39' 48" N
		LONGITUDE 98° 24' 18" W
	+551.5	WATCH: FAST, CORR -13s
		TEMP: +30°F
1053.2	+546.8	STA SD 260 IS 10 METERS
5356.2	+556.2	S. OF BLDG 3077, STATION
		IS 0.30 CAL CARTRIDGE
		CASE SET IN TRIANGULAR
		CONCRETE BLOCK. AZ MK
	+581.1	IS SHAFT SUPPORTING
		LIGHT ON TOP OF WATER
1020.9	+579.1	TOWER.
5383.1	+583.1	
	+623.7	
0979.5	+620.5	
5426.9	+626.9	

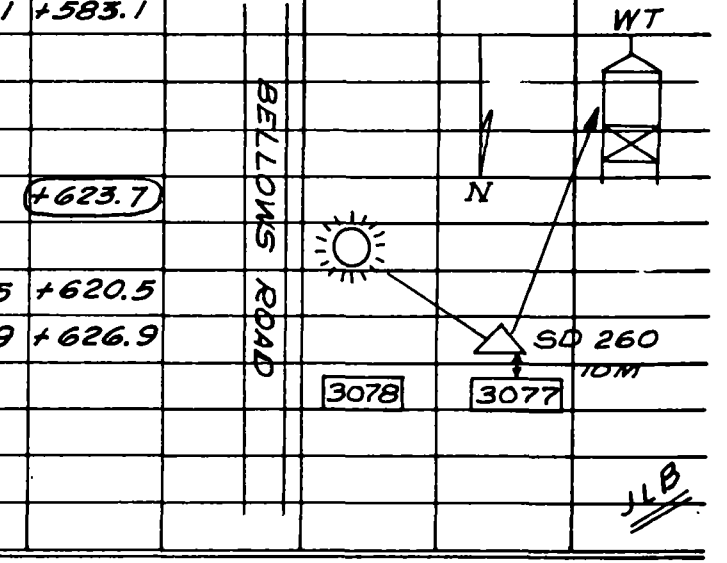


Figure 8–14. Sun observation, altitude method notes, 0.2 mil theodolite.

STAR OBSERVATION

DESIGNATION HOUR ANGLE METHOD DATE 4 APRIL 1969

WEATHER: COOL–WINDY

CHIEF OF PARTY: SSG GROOM
INST. OPR: SP4 BARTH
RCDR: SP4 MUNOZ

INST: 0.2MIL NO. 1769

STATIO	T	h	m	s	HORIZONTAL ∠ MILS	MEAN
FINN	D				0001.0	
	R				3201.0	0001.0
SD 340	MN ∠	19	28	50	2923.2	
POLARIS	D	19	28	16	2924.2	
	R	19	29	25	6124.2	2924.2
FINN	D				0001.0	
	R				3201.0	0001.0
SD 340	MN ∠	19	40	22	2922.8	
POLARIS	D	19	38	55	2923.8	
	R	19	41	50	6123.7	2923.8
FINN	D				0001.0	
	R				3201.0	0001.0
SD 340	MN ∠	19	48	58	2922.4	
POLARIS	D	19	47	45	2923.5	
	R	19	50	10	6123.4	2923.4

REMARKS

LATITUDE: 34° 39' 47" N
LONGITUDE: 98° 24' 21" W
WATCH: SLOW; CORR + 5^6

STA SD 340 IS 60 METERS OF BLDG 3077. STA IS 0.30 CAL CARTRIDGE CASE SET IN TRIANGULAR CONCRETE BLOCK. AZ MK IS STA FINN, JUST S OF HOSKINS RD, AND E. OF RED SHACK

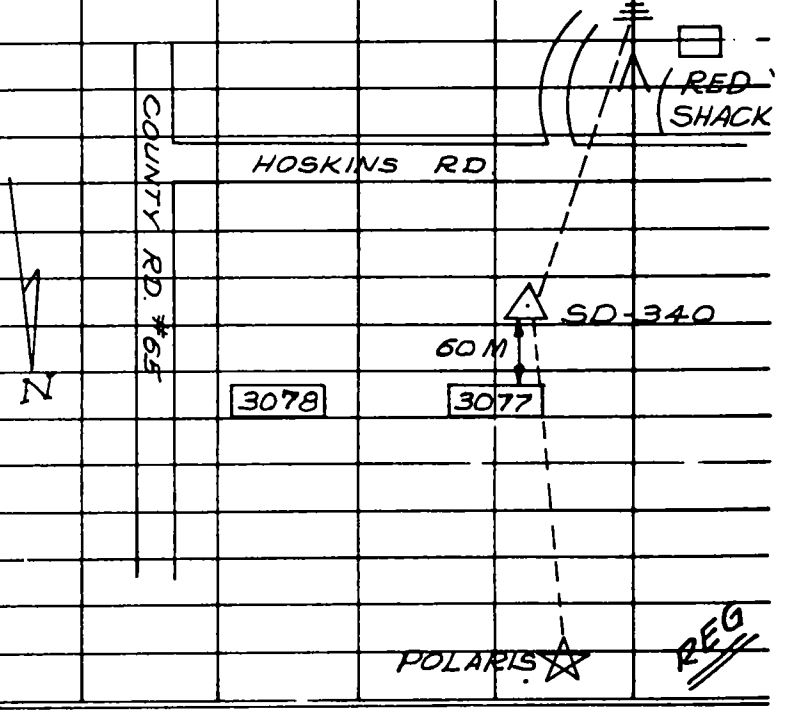


Figure 8–15. Polaris observation notes, hour angle method.

DESIGNATION AZIMUTH GYRO DATE 7 APRIL 1969

STATION	GYRO	T	HORIZONTAL READING	MEAN
	FWD	D	6011.111	
		R	2811.121	6011.116
BNSCP		MN AZ	6011.228	
AZ MK	REV.	D	6011.333	
		R	2811.347	6011.340
	FWD	D	6011.237	
		R	2811.240	6011.238
BNSCP		MN AZ	6011.304	
AZ MK	REV	D	6011.366	
		R	2811.372	6011.36
	FWD	D	6011.150	
		R	2811.132	6011.141
BNSCP		MN AZ	6011.182	
AZ MK	REV	D	6011.216	
		R	2811.233	6011.224

CHIEF OF PARTY: SGT. EAST

WEATHER: COOL-CLOUDY INST. OPR: SP4 VILLA

RCDR: SP4 CROSSLY

INST: ABLE SYSTEM 137

REMARKS

BNSCP IS 215 METERS W OF E DIABLO VALLEY RD, 290 METERS N OF INTERSECTION WITH DRY GULCH RD. STA IS TACK IN 2"x 2" HUB, FLUSH WITH GROUND. AZ MK IS CROSS ON STEEPLE, GUADLUPE CHURCH, 2000 METERS NNW OF BNSCP. SELECTIVITY SWITCH IN "MED."

MEAN SET 1 6011.228

MEAN SET 2 6011.304

MEAN SET 3 6011.182

SUM 3 18033.714

6011.238

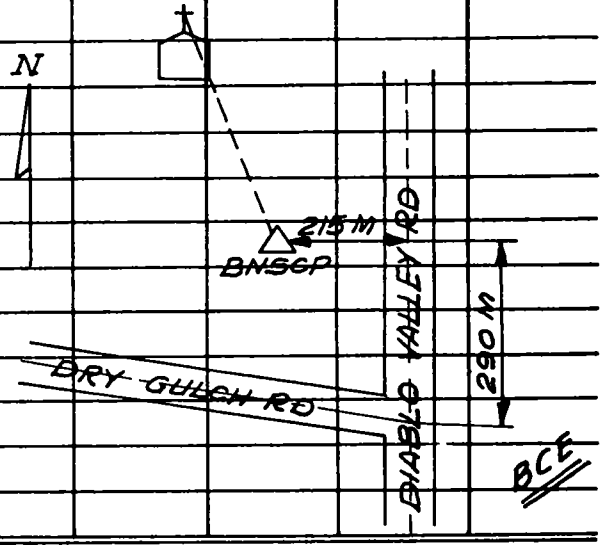


Figure 8–16. Azimuth gyro notes for azimuth determination.

SIMULTANEOUS OBSERVATION

DESIGNATION MASTER STATION DATE 30 MAR 19 69

WEATHER: COOL-CLEAR
CHIEF OF PARTY: SSG GREEN
INSTR OPR: SP4 MITCHELL
INST: .002 MIL NO 1881
RCDR: SP4 MANN

STATION	T	HORIZONTAL ∠ MILS	MEAN	VERTICAL READING	VERTICAL ∠ MILS
WT	D	0000.143			
	R	3200.148	0000.146		
ADAMS	MN ∠	6049.422			393.674
SUN	D	6048.172		1197.023	402.977
	R	8850.964	6049.568	5184.370	384.370

REMARKS

STA ADAMS, MASTER STA, IS 15 METERS SW OF JUNCTION DUMP RD AND EL RD STA IS 1" PIPE SET IN 6"x6" CONCRETE BLOCK FLUSH WITH GROUND. AZ MK IS LIGHTING ROD ON TOP OF WATER TOWER 1000 METERS SW OF STA ADAMS.

COMPUTATION OF AZ TO SUN

AZ ADAMS TO WT 4306.243
+ ∠ WT-ADAMS-SUN 6049.422
10355.665
− 6400.000
AZ ADAMS TO SUN 3955.665

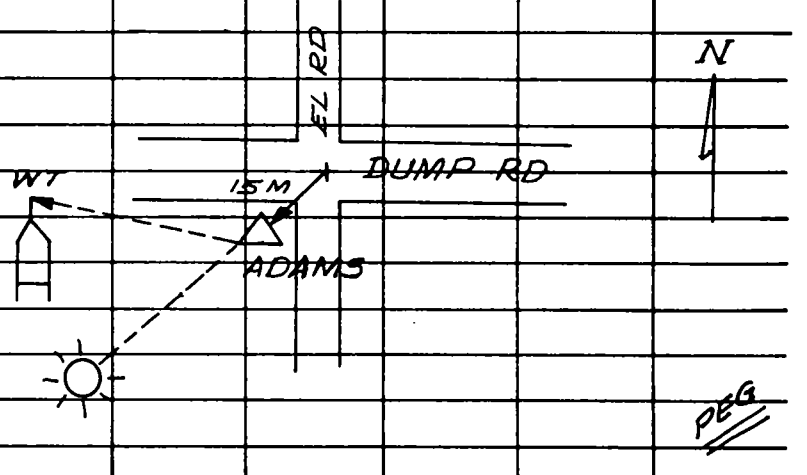


Figure 8–17. Simultaneous observation, master station notes.

SIMULTANEOUS OBSERVATION

DESIGNATION FLANK STATION DATE 25 MAR. 1969

STATION	T	HORIZONTAL ∠ MILS	MEAN		
STA 21	D	0001.0			
	R	3201.0	0001.0		
STA 20	MN. ∠	(1193.5)			
SUN	D	1191.1			
	R	4397.9	1194.5		

WEATHER: COOL-CLEAR
INST: 0.2 MIL
NO. 2113

CHIEF OF PARTY: 33G HUFF
INST. OPR: SP4 MARTIN
RCDR: SP4 BEHM

REMARKS

STA 20, FLANK STA, IS 30 METERS SW OF FORD ON DUMP RD, 5 METERS N. OF LARGE BOULDER. STA 21, AZ MK, IS 240 METERS S. OF STA 20, 43 METERS W. OF LONE TREE. BOTH STATIONS ARE MARKED BY NAILHEADS IN 6"x6" CONCRETE BLOCKS PROJECTING 2" ABOVE GROUND.

COMPUTATION OF AZ STA 20 TO STA 21

AZ MASTER (ADAMS) TO SUN 3955.7
CORRECTION +.5
3956.2
-∠ STA 21-STA 20-SUN - 1193.5
AZ STA 20-STA 21 2762.7

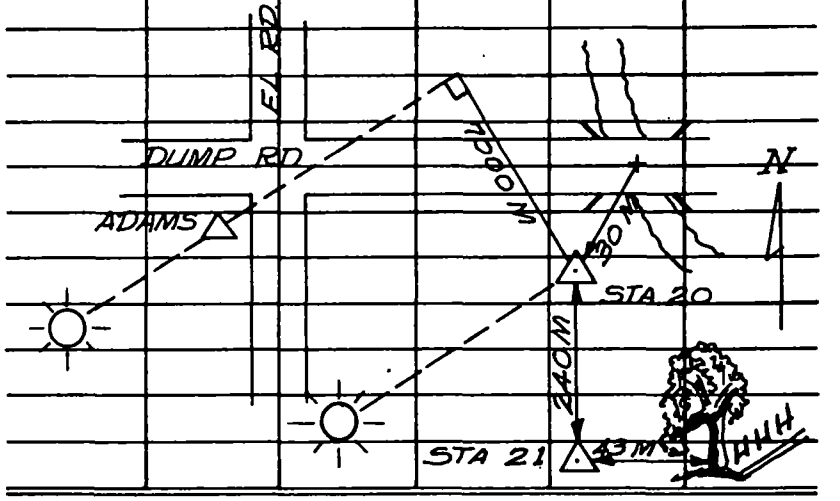


Figure 8–18. Simultaneous observation, flank station notes.

CHIEF OF PARTY: SSG KOSCIN

WEATHER: CLEAR-COLD INST. OPR: SP4 BRYON

INST: M2 (AC) NO 1798 RCDR: SP4 DAVIS

DESIGNATION DECLINATION DATE 5 JAN. 19 67

STA.	GRID AZ.	DECLINATION CONSTANT	TRUE VERT. ∠	OBSERVED VERT. ∠	VERTICAL ∠ CORR.
TED					
MB2	0852.4	6395.5	+10.3	+10.5	-0.2
SIGNAL MT.	5249.8	6394.0	+38.0	+39.0	-0.1
MN		(6394.8)			(-0.6)

NOTE: (1) IF TWO AZ MKS ARE NOT AVAILABLE MAKE TWO OBSERVATIONS TO ONE AZ MK.

(2) DECLINATION CONSTANTS MUST AGREE WITHIN 2 MILS.

(3) VERTICAL ANGLE CORRECTIONS MUST AGREE WITHIN 1 MIL

REMARKS

STA. TED IS 1 MILE S. OF WOLF TOWER ON TOWER TWO ROAD. STA IS OPPOSITE 1000 INCH RANGE FLAGPOLE, 18.3 METERS E. OF TOWER TWO RD ℄. STA IS BRONZE DISK STAMPED "TED." BLACK ℄ WHITE WOOD SIGN IS 2 METERS E. OF STA. AZ MKS. ARE QUAD MARKERS ON MC KENZIE HILL, SIGNAL MOUNTAIN, MB 2 AND THE LIGHT ON "SOUTHWEST WATER TOWER."

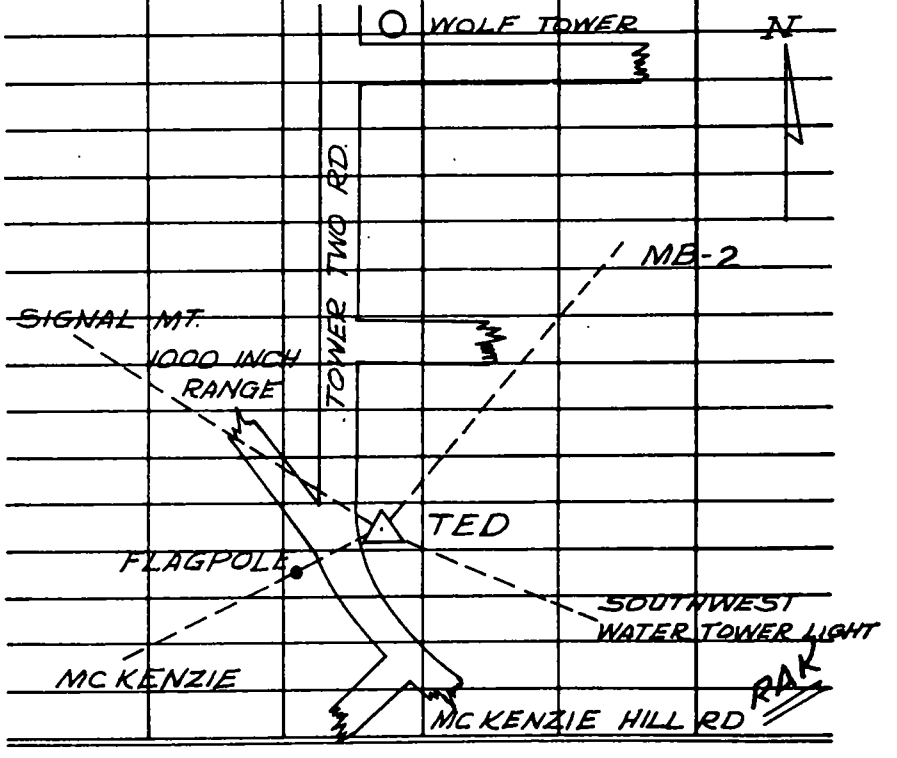


Figure 8–19. Recorder's notes, declinating aiming circle.

CHAPTER 9
TRAVERSE

Section I. GENERAL

9-1. General

In surveying, traverse is defined as the field operation of measuring the lengths and directions of a series of straight lines connecting a series of points on the earth. Each of these straight lines is called a traverse leg and its length is determined by direct measurement with a 30-meter steel tape or by other distant measuring devices. Each point is called a traverse station. At each traverse station, a horizontal angular measurement is taken and is used to determine the azimuth of the next traverse leg. These measurements are used to compute the relative horizontal positions of each unknown traverse station on some system of coordinates, such as the Universal Transverse Mercator grid system. A vertical angle is also measured at each station and is used to determine the height above mean sea level of each of the unknown traverse stations. In field artillery surveys, the angular measurements may be made by using one of three instruments, depending on the accuracy required and the echelon at which the traverse is conducted. These instruments are the aiming circle (1:500 accuracy), the 0.2 mil theodolite (1:1000 accuracy) and the 0.002 mil theodolite (1:3000 accuracy).

9-2. Field Work

In a traverse, three stations are considered to be of immediate significance (fig 9-1). These stations are referred to as the *rear station*, the *occupied station* and the *forward station*. The rear station is that station from which the persons performing the traverse have just been moved or a point to which the azimuth is known. The occupied station is the station at which the party is located and over which the surveying instrument is set. The forward station is the next station in succession and is the immediate destination of the party. Field measurements for the traverse are as follows:

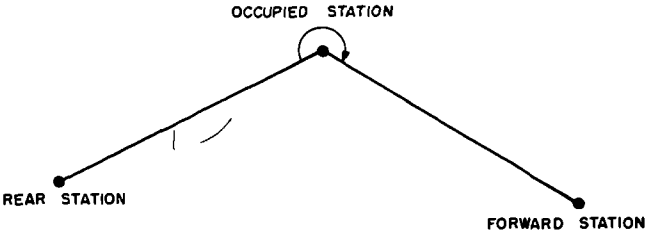


Figure 9-1. Diagram illustrating stations of immediate significance.

a. Horizontal Angles. Horizontal angles are determined from instrument readings measured at the occupied station by sighting the instrument on the rear station and turning the instrument clockwise to the forward station. When measuring horizontal angles, the instrument is always sighted at the lowest visible point of the station marker designating the rear and forward stations.

b. Vertical Angles. Vertical angles are determined from instrument readings made at the occupied station to the height of instrument (HI) on the station marker (usually a range pole) at the forward station. When the distance between two successive stations in a traverse exceeds 1,000 meters, then the vertical angle must be measured reciprocally (the vertical angle is measured from each end of that particular traverse leg). This procedure (reciprocal measurement) is used to eliminate errors caused by curvature and refraction (see app D).

c. Distance. The distance is horizontally taped in a straight line between the occupied station and the forward station or is determined by using electronic distance measuring devices.

9-3. Starting Control (Traverse Requirements)

The three basic requirements for a traverse are the distance between traverse stations, the azi-

muth of a line between successive stations, and a vertical angle from each occupied station to the next successive forward station (fig 9–2). Since the purpose of traverse is to locate the unknown points relative to each other and to locate all points within the traverse relative to a common grid, two other elements constituting starting data are needed. They are the coordinates and height of a starting point and an azimuth to a visible azimuth mark (fig 9–3). These additional requirements may be obtained from sources indicated as follows:

a. Available Control. Starting control may be available in an existing trig list, or the survey element of a higher headquarters may provide data for a survey control point. An azimuth to an azimuth mark (starting direction) may be obtained by use of an azimuth gyro surveying instrument, by astronomic observation, by computation from known coordinates, or by reference to an existing trig list.

b. Maps. If there is no known control available, a careful map inspection may be used to determine starting coordinates and height. (For survey purposes, data scaled from a map is considered to be assumed data.) If at all possible, a starting azimuth should be determined by using an azimuth gyro surveying instrument or by astronomic observation. If the situation is such that either of these methods cannot be utilized, then a starting azimuth may be obtained by carefully scaling from a large scale map or by using a declinated aiming circle.

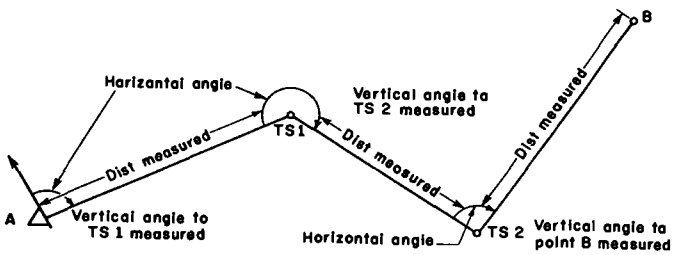


Figure 9–2. Diagram of a traverse.

c. Assumed. When neither known control nor maps are available, the coordinates and height for the starting station may be assumed. Starting direction can be determined by the most accurate means available, as discussed in *a* and *b* above.

9–4. Types of Traverse

There are basically three types of traverse used in field artillery survey. These are open traverse, closed traverse (of which there are two kinds: closure on second known point and closure on starting point), and directional traverse.

a. Open Traverse. An open traverse begins at a point of known coordinates and ends at a station whose relative position is not previously known. The open traverse is considered to be the *least desirable* type of traverse because it provides no check on the accuracy of the starting control nor does it provide any check on the accuracy of the fieldwork. For this reason, traverses are never deliberately left open and are always closed as soon

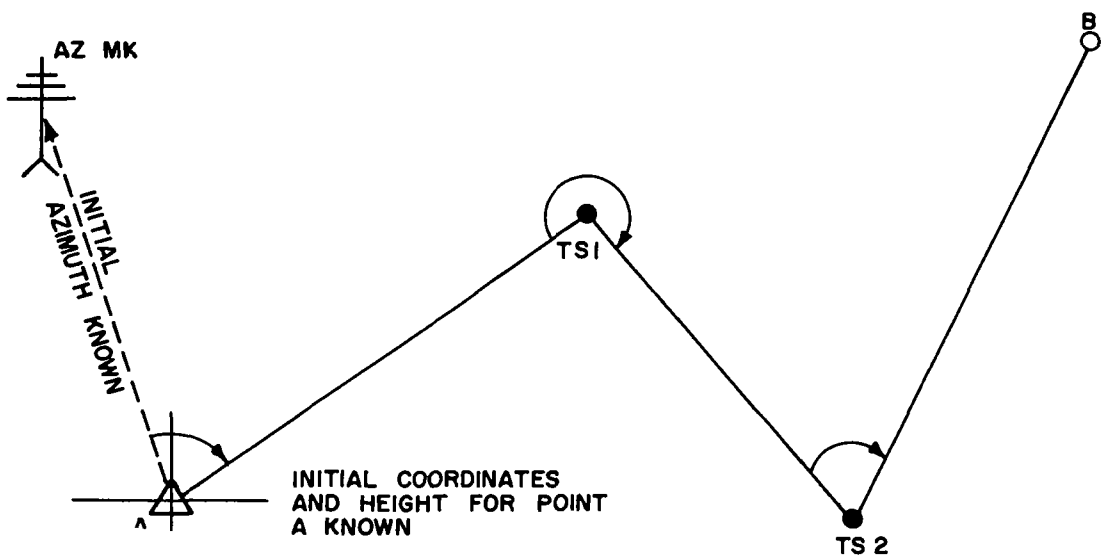


Figure 9–3. Diagram of a traverse with starting data.

as possible. Open traverses are used only when time or the enemy situation does not permit a closure on a known point.

b. Closed Traverses on Starting Points. This type of traverse begins at a point of known coordinates, moves through the various required unknown points and returns to and terminates at the starting point. This type of closed loop traverse is considered as the *second best* and is used when both time for survey and limited survey control are considerations. It will provide checks on fieldwork and computations and will afford a basis for comparison to determine the accuracy of the work performed. However, this type of traverse does not provide a check on the accuracy of the starting data nor does it insure detection of any systematic errors which might have been made.

c. Closed Traverse on Second Known Point. This type of traverse begins from a point of known coordinates, moves through the various required unknown points and then terminates at a second point of known coordinates. The point on which the survey is closed must be a point which was established to an equal or higher order of accuracy than that of the starting point. This is the *most preferred* type of traverse. It will provide checks on fieldwork, computations, and the starting coordinates as well as afford a basis for comparison to determine the accuracy of the work performed.

d. Directional Traverse. A directional traverse is a type of traverse which extends directional (azimuth) control only. This type of traverse can be either open or closed; if open, the traverse should be closed at the earliest opportunity. It can be closed either on the starting azimuth, or another azimuth of equal or a higher order of accuracy, by astronomic observation, or by an azimuth gyro surveying instrument. Since direction is the most critical element of field artillery survey and time is frequently an important element to be considered, it is sometimes necessary at lower echelons to map spot battery locations and extend direction only.

9–5. Traverse Stations

a. Selection of Stations. In field artillery survey, sites for traverse stations normally are selected as the traverse progresses. The stations must be located so that at any one station both the rear and forward stations are visible. Some brush cutting may be required to clear lines of sight between stations. If the distance is to be measured with a tape, the line between stations must be free of obstacles for the taping team. Electronic lines of sight (para 6–26) must also be free of obstructions if electronic equipment is to be used. The number of stations in a traverse should be kept to a minimum to reduce the accumulation of instrumental errors and the amount of computation required. Short traverse legs require the establishment and use of a greater number of stations and may cause excessive errors in azimuth because small errors in centering and pointings will be magnified and reflected in the azimuth closure.

b. Station Markers. Traverse station markers are usually 1-inch by 1-inch wooden stakes, 6 inches or more in length. These stakes, called hubs, are driven flush with the ground. The center of the top of the hub is marked with a surveyor's tack or with an X to designate the exact point of reference for angular and linear measurements. To assist in recovering the station, a reference (witness) stake is driven into the ground so that it slopes toward the station (fig 9–4). The identification of the station is written on the reference stake with a lumber crayon or a china marking pencil or on a tag attached to the stake. Signal cloth may also be tied to the reference stake to further assist in identifying or recovering the station. During phases of survey expansion, more permanent types of markers may be used such as shell casings or concrete monuments. For details

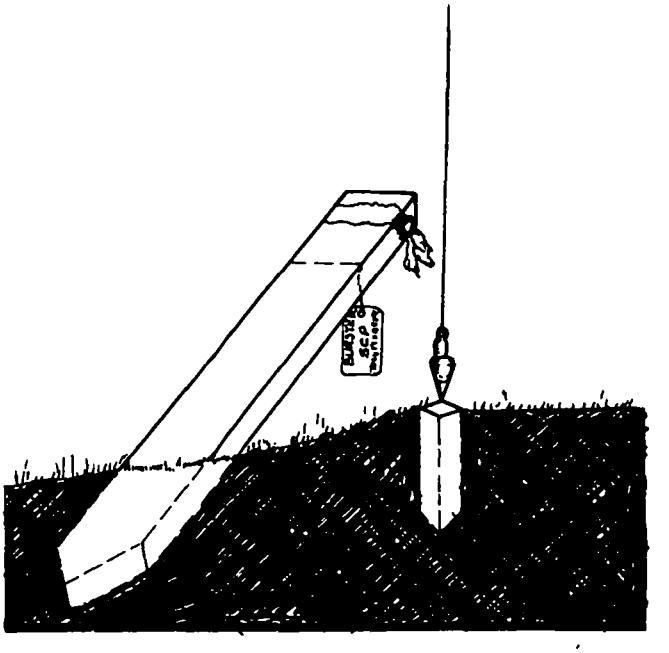


Figure 9–4. A survey station marked wtih a reference stake.

on setting and referencing concrete monuments, see TM 5–441.

c. Station Signals. Signals must be erected over survey stations to provide a sighting point for the instrument operator and to serve as a reference for tape alinement by the taping team. Permanent tripods or similar signals have been erected over some primary survey control stations so that the stations can be occupied without disturbing the signal. In artillery survey, in which most of the station sites are selected and marked as the field-work progresses, temporary signals must be erected at the stations as they are needed. The equipment used for station signals in artillery survey includes:

(1) *Range poles.* The range pole is constructed of tubular steel and consists of two interlocking sections. The length of the assembled pole is 6½ feet, and one end is tapered to a point. The pole is painted in 1-foot sections with alternate colors of red and white. For storage, the pole is disassembled and placed in a canvas case. In use,

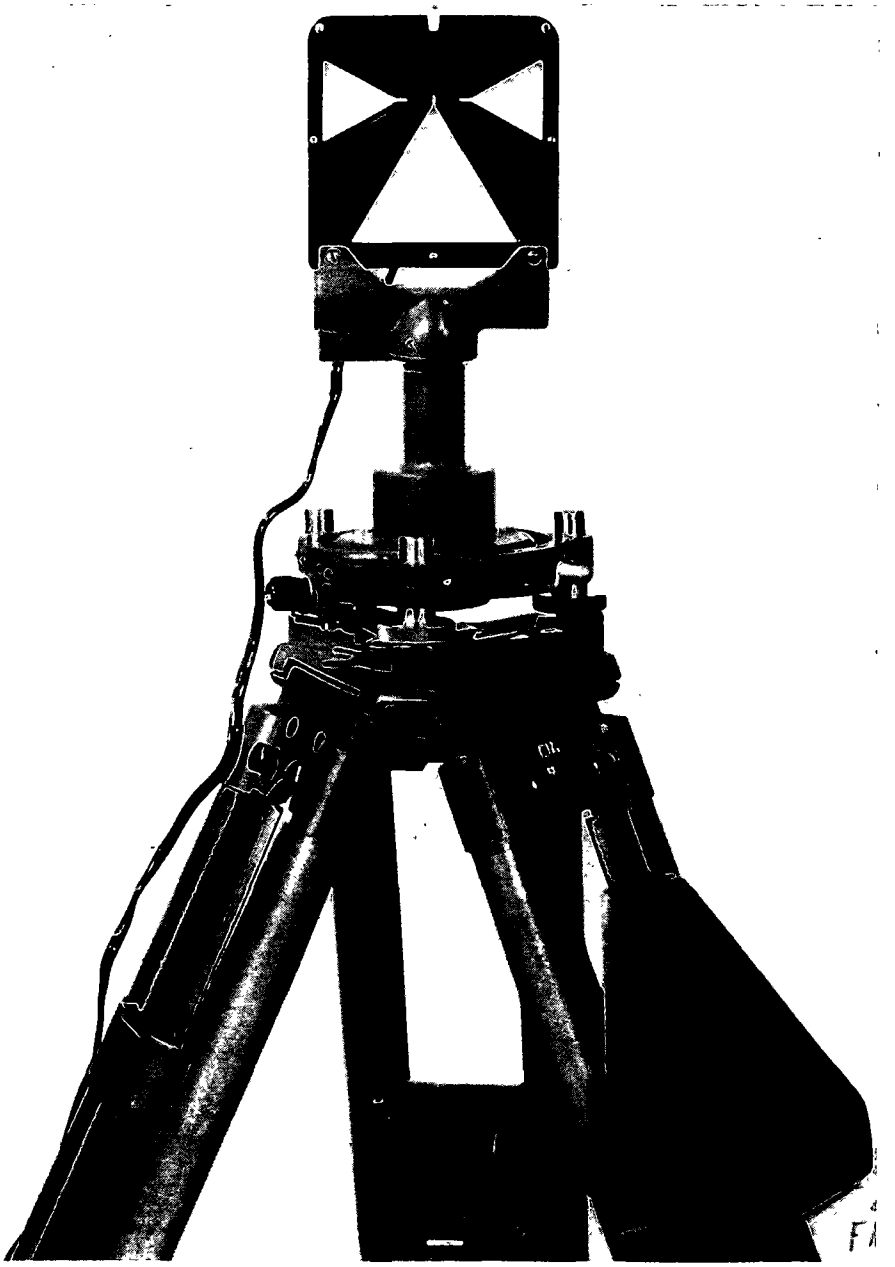


Figure 9–5. Tripod-mounted target.

the tapered point of the range pole is placed on the station mark, and a rod level is used to make the pole vertical for observations. The angular portion of the level is placed against the pole, with the circular level vial up. The top of the pole is then moved until the bubble in the vial is centered. The verticality of the range pole should be checked by verifying that the bubble remains centered at other points on the range pole. The range pole is maintained in a vertical position throughout the observing period normally by use of a range pole tripod. To prevent the measurement of angles to the wrong point, the range pole should be placed in a vertical position only when it is being used to mark a survey station.

(2) *Target set, surveying.* The target set (fig 9–5) is used to mark the end of the orienting line by artillery missile batteries that have special accuracy requirements for the azimuth of the orienting line. The target set may also be issued to field artillery survey elements that are required to perform survey to fourth-order accuracy. The target is mounted on the same tripod that is used with the 0.002 mil and 0.2 mil theodolites. The tripod is set up, leveled, and plumbed in the same manner as for the theodolites. After setup, the target is oriented so that it can be seen directly by the instrument which is sighting on it. The target can be illuminated for night use. Greater accuracy is obtained on short traverse legs by using the target rather than range poles. The crosshairs in the telescope should bisect the triangles of the target when sighting on it. Flexibility can be obtained by interchanging and leapfrogging theodolites and targets with tripids and tribrachs left in place, thus reducing setup time. The longitudinal level and optical plummet on the target must be adjusted in the same manner as for the 0.002 mil theodolite.

9–6. Organization of Traverse Parties

The number of personnel authorized to perform survey will depend on the unit's table of organization and equipment (TOE). The organization of these persons into a traverse party and the duties assigned to each member will depend on the unit's standing operating procedure (SOP). The organization and duties of traverse party members and modifications proposed for reduced strength parties given in *a* and *b* below are based on the functional requirements of a traverse. See appendix C for a detailed description of duties of individuals.

a. Traverse Party (Fifth-Order).

(1) *Chief of party.* The chief of party selects and marks the locations of the traverse stations and supervises the work of the other members of the party. He also assists the survey officer in the reconnaissance and planning of the survey.

(2) *Instrument operator.* The instrument operator measures the horizontal and vertical angles at each traverse station. He is responsible for the care and cleaning of his instrument. He also operates the azimuth gyro and the electronic measuring equipment (DME), when the DME is authorized by the TOE.

(3) *Recorder.* The recorder keeps the field notes for the party in a field notebook. He records the angles measured by the instrument operator, the distances measured by the tapemen, and all other data pertaining to the survey. He also checks the length of each traverse leg by pacing.

(4) *Two computers.* The computers compute the grid coordinates and height of each traverse station as the traverse progresses. The two computers work independently and check their *results* with each other.

(5) *Two rodmen-tapemen.* When tapes are used, the tapemen measure the distance from one traverse station to the next. Each tapeman keeps a record of the distance taped. The two tapemen compare their recorded distances before reporting the measured distance to the recorder. The tapemen maintain all taping equipment.

b. Traverse Party (Taped, Fourth-Order). Same as in *a* above with the following two exceptions:

(1) The recorder is not required to check the length of the traverse leg by pacing.

(2) Two additional rodmen-tapemen (total of four) are authorized. In artillery fourth-order traverse, all distances are double-taped to a *comparative* accuracy of 1:5,000.

c. Traverse Party (Electronic Distance Measuring Equipment). The electronic distance-measuring equipment traverse party is equipped with three 0.002-mil theodolites and three electronic distance measuring devices. The personnel are one chief of party, three instrument operators, three recorders, two computers, and one rodman. This party normally would function as shown in figure 9–6.

d. Reduced-Strength Party. Often sufficient men are not available to perform a traverse. Under such circumstances, other members of the survey party may be required to perform more than one function. Shortages in personnel will never affect

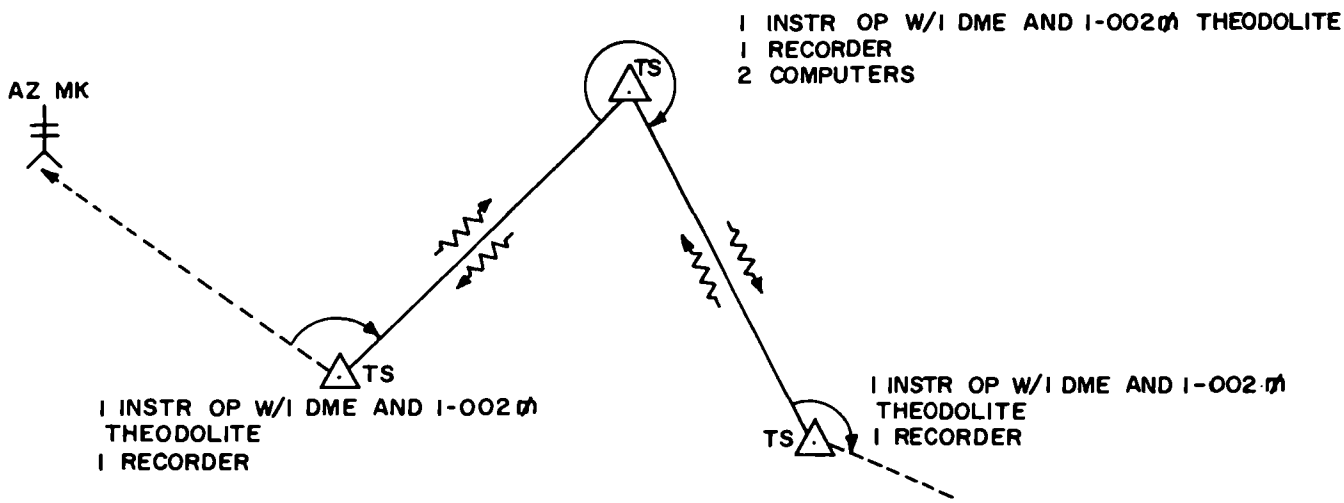


Figure 9-6. Diagram illustrating normal operation of DME traverse paty.

the jobs of instrument operator or tapemen, since these two functions must be performed if a traverse is to be conducted. Shortages will, therefore, be apparent in the duties of the rodmen, the computers, and the recorder. If the party is short one rodman, the chief of party will perform, in addition to his own duties, the duties of the rodman. If the party is short one computer, the recorder will also compute. If three or more men are absent from the party, the fieldwork is completed, and the computations are performed later by designated personnel. The organization of a reduced strength party is not bound by strict rules. However, for a party to function when personnel shortages exist, each party member must be trained to perform all duties.

9-7. Night Traverse

At times, the field artillery surveyor will be required to survey at night to accomplish his mission. This can be done by a modification of daylight techniques and organization. However, night traverses require more work, more training, more personnel, and more coordination.

a. Equipment Required for Night Traverse. The same equipment used in a daylight traverse is also used in a night traverse with the addition of the necessary lighting equipment. Included in this lighting equipment are flashlights for all personnel and two target lights for each range pole. If aiming post lights are not available, two flashlights for each range pole will suffice. All lighting devices should be equipped with a filter of some type to insure greater light security and to prevent undue glare in the telescope of the observing instrument when it is pointed at a station. The observing instrument should be equipped with its integral lighting equipment.

b. Personnel. The standard traverse party must be supplemented with additional personnel to enable it to function properly at night. Three additional men who are light holders accompany and assist the tapemen.

c. Station Marking. At night the traverse stations are marked the same as in daylight except for the lighting devices required at the rear and forward stations. Two target lights should be placed on each range pole (usually two range poles —both the rear and the forward stations) which will be observed from a traverse station. One of these lights should be placed on the pole at the height of instrument and other at the lowest point visible from the instrument. Both lights should be pointed directly at the observing instrument. If target lights are not available, flashlights may be taped or securely strapped to the pole in the same manner prescribed for the target lights. To insure that the lights are placed and pointed properly, the chief of party will designate one man to remain with the range poles and coordinate the placement and pointing of the lights with the instrument operator.

d. Angle Measuring and Recording.

(1) *Angle measuring.* There is no difference in measuring angles at night and measuring them in daylight except that at night the instrument must be equipped with a night lighting device. The

chief of party should coordinate with the instrument operator to insure that the lights on the rods are placed and pointed properly and are moved to the next station when the observation is completed.

(2) *Recording.* The recording procedures used during daylight are used at night except that the recorder must be supplied with a flashlight so that he can see to record. He should record in the remarks section of the field notes anything which may have an effect on the survey—burned-out lights, only one light on forward station, etc.

e. Taping. For information on taping at night, see paragraph 6–17.

f. Communication. Communication during a night traverse should be conducted by radio. However, radio is not always convenient or available, and at times the survey party must resort to light signals. These light signals should be prearranged and simple. For example, the instrument operator may have to signal the rodman to raise or lower the bottom light on a range pole or inform him to move to the next station. In arranging signals, the survey party should avoid waving the lights, since a waving light may easily attract the enemy's attention. Every precaution should be taken in sending light signals to avoid detection by the enemy.

9–8. Traverse Field Notes

For correct procedures and examples of field notes on traverse, see paragraphs 8–1 through 8–5 and figures 8–4 through 8–7.

Section II. TRIGONOMETRY OF TRAVERSE

9–9. Extending Azimuth

In artillery survey, direction may be defined as the angular measurement between a specific reference line and a given line. *Azimuth* is the term used in artillery survey to describe direction, and is the horizontal clockwise direction from a reference line (Grid North) to a given line. Every line has two azimuths, dependings on the observer's position on the line. In figure 9–7, a survey is progressing from A toward B. Then, the angle *a* is the forward azimuth for the line A to B. To designate the azimuth from B to A, the angle *b* is used. This is known as the back azimuth of the line. The forward and back azimuth of a line differ by 3200 m for artillery survey purposes.

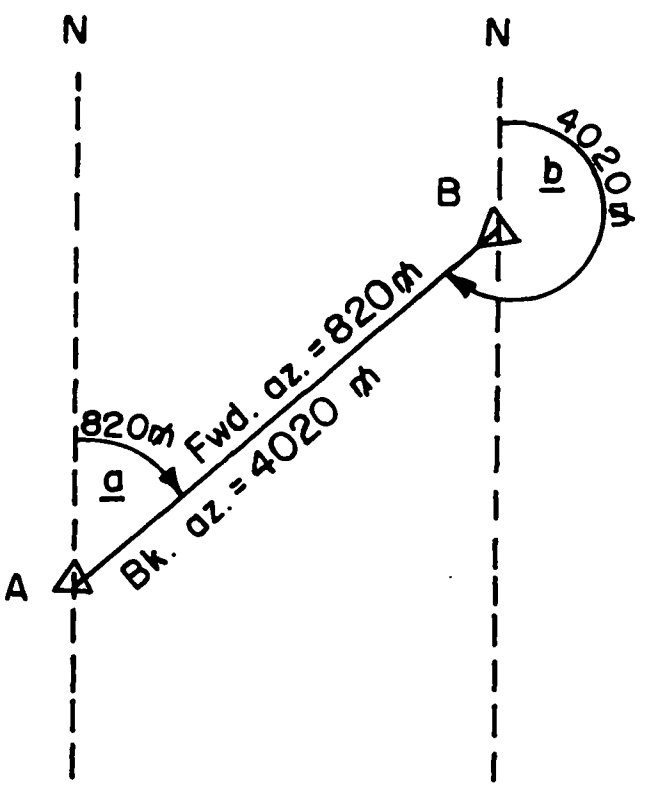


Figure 9–7. Azimuth and back azimuth.

In order for a traverse to be computed, an azimuth to the forward station must be determined for each leg of the traverse. This is accomplished for each succeeding leg of the traverse by adding the value of the angle determined at the occupied station between the rear station and the forward station to the azimuth from the occupied station to the rear station. The example (*a* and *b* below) illustrates this procedure. It should be noted that on occupation of each successive station the first step is to compute the back-azimuth of the preceding traverse leg.

a. Example Problem.

(1) *Given.*

Azimuth from station A to az mk	5592.6 mils
Angle az mk–A–TS1	2134.0 mils
Angle A–TS1–TS2	3820.5 mils
Angle TS1–TS2–B	1756.5 mils

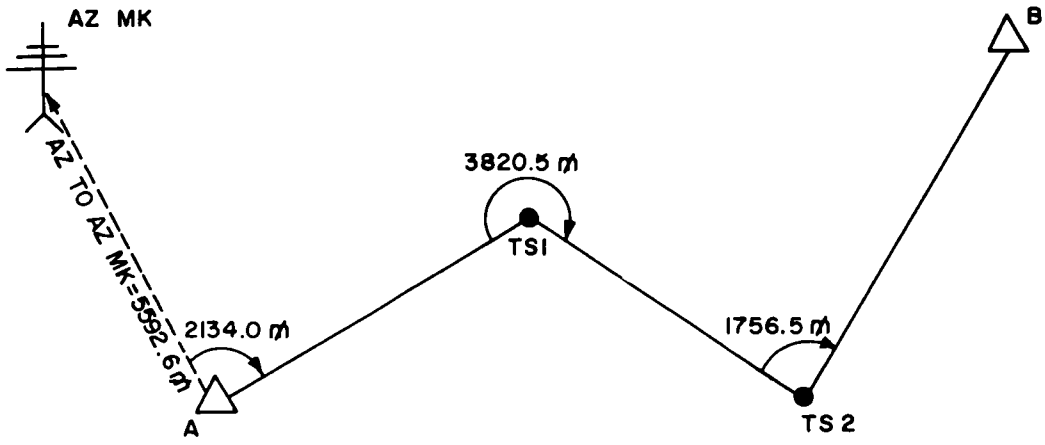
(2) *Required.*

Azimuth from station TS2 to B.

b. Solution.

(1) *At station A—*

Azimuth from A to az mk	=	5592.6 mils
(+) Angle az mk–A–TS1	=	2134.0 mils
Sum	=	7726.6 mils
(—) a full circle	=	6400.0 mils
Azimuth A to TS1 (fwd az)	=	1326.6 mils



Note: Azimuth from point A to azimuth mark is known.

Figure 9-8. Diagram of determination of azimuths.

(2) *At station TS1*—

Azimuth from station A to	=	1326.6 mils
TS1 (+) a half circle	=	3200.0 mils
Azimuth from TS1 to A (bk az)	=	4526.6 mils
(+) Angle A-TS1-TS2	=	3820.5 mils
Sum	=	8347.1 mils
(—) a full circle	=	6400.0 mils
Azimuth TS1 to TS2 (fwd az)	=	1947.1 mils

(3) *At station TS2*—

Azimuth from TS1 to TS2	=	1947.1 mils
(+) A half circle	=	3200.0 mils
Azimuth from TS2 to TS1 (bk az)	=	5147.1 mils
(+) Angle TS1-TS2-B	=	1756.5 mils
Sum	=	6903.6 mils
(—) A full circle	=	6400.0 mils
Azimuth TS2 to B (fwd az)	=	503.6 mils

9-10. Azimuth and Bearing Angle Relationship

a. An azimuth is required in traverse to permit the determination of a bearing angle. The bearing angle of a traverse leg and *not* the azimuth is used in traverse computations for the determination of differences in coordinates. The bearing angle of a line is the *acute angle* formed by the interesction of that line with a grid north-south line. Figure 9-9 illustrates the relationship between the azimuth of a line and its bearing angle.

b. In artillery survey, the horizontal plane (or circle) is divided into four quarters. Each one-quarter circle contains 1600 mils and is called a *quadrant.* The four quadrants are numbered in a clockwise direction (since azimuths are measured in a clockwise direction) beginning at Grid North and proceeding around the circle using Roman numerals I-IV. They are as follows:

Quadrant I = 0-1600 mils
Quadrant II = 1600-3200 mils
Quadrant III = 3200-4800 mils and
Quadrant IV = 4800-6400 mils

9-11. Determination of Bearing Angles

The manner in which bearing angles are computed from a given azimuth depends on the quadrant in which that azimuth lies (fig 9-10).

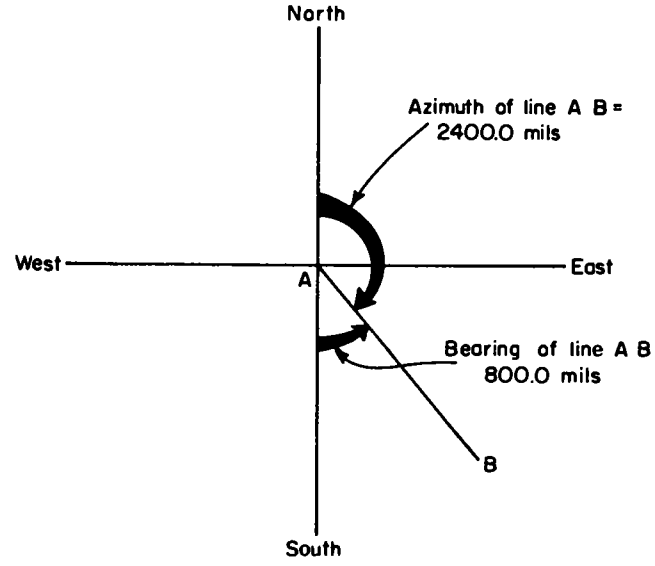


Figure 9-9. Sketch illustrating azimuth bearing relationship.

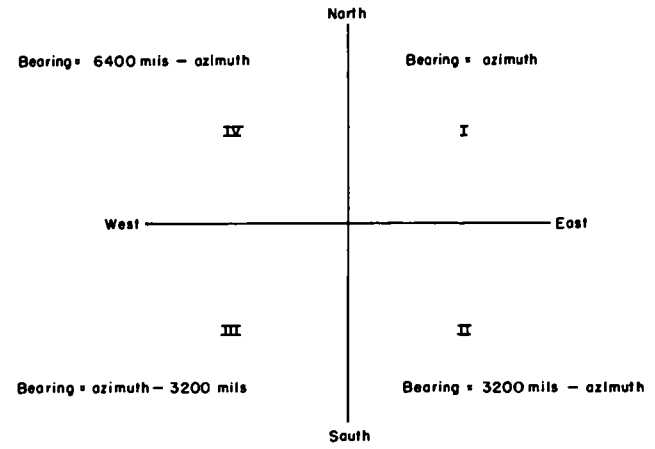


Figure 9–10. Sketch illustrating determination of bearing angle.

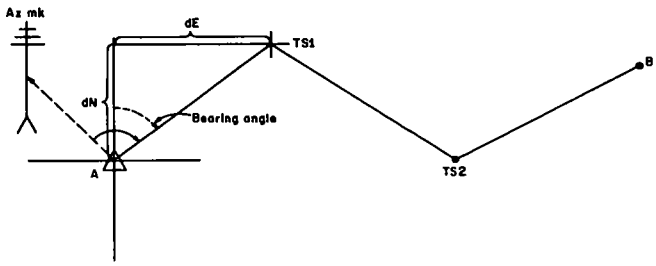


Figure 9–11. Schematic diagram illustrating dE and dN requirements.

a. When the azimuth is in the first quadrant, 0 mil to 1,600 mils, the bearing is equal to the azimuth.

b. When the azimuth is in the second quadrant, 1,600 mils to 3,200 mils, the bearing is equal to 3,200 mils minus the azimuth.

c. When the azimuth is in the third quadrant, 3,200 mils to 4,800 mils, the bearing is equal to azimuth minus 3,200 mils.

d. When the azimuth is in the fourth quadrant, 4,800 mils to 6,400 mils, the bearing is equal to 6,400 minus the azimuth.

9–12. Trigonometry and the Traverse Leg

a. If the coordinates of a point are known and the azimuth and distance from that point to a second point are known, the coordinates of the second point can be determined. In figure 9–11, the coordinates of Station A are known and the coordinates of TS1 are to be determined. The azimuth and distance from Station A to TS1 have been determined by turning the horizontal angle at Station A from the azimuth mark to TS1 and by measuring the horizontal distance from Station A to TS1. The grid easting and grid northing lines through each of the points are shown.

b. The determination of the coordinates of TS1 requires the solution of a right triangle. The intersection of the NS line through Station A and the EW line through Station TS1 form a right angle (1600 m or 90°); the known side A–TS1 (measured distance) becomes the hypotenuse and the bearing angle at Station A is determined from the azimuth of Station A to TS1. Thus a right triangle is formed.

9–13. Coordinate Computations

The two unknown sides of this right triangle are designated the difference in easting coordinates (dE) and the difference in northing coordinates (dN). To compute the length of sides dE and dN, two of the trigonometric functions of a right triangle are used as follows:

To determine dE:

$$\text{Sine of bearing angle} = \frac{\text{opposite side}}{\text{hypotenuse}} = \frac{\text{dE}}{\text{distance}}$$

or,

dE = sine of bearing angle X distance.

To determine dN:

$$\text{Cosine of bearing angle} = \frac{\text{adjacent side}}{\text{hypotenuse}} = \frac{\text{dN}}{\text{distance}}$$

or,

dN = cosine of bearing angle X distance.

To determine the coordinates of the unknown point (Sta TS1), the difference in easting coordinates (dE) is added algebraically to the easting coordinates of the known point (Sta A) and the difference in northing coordinates (dN) is added algebraically to the northing coordinate of the known point (Sta A). In figure 9–12, the traverse leg appears in the first quadrant. It is for this reason that the dE and the dN must be added to the easting and northing coordinates of Station A. If the location of the traverse leg were in one of the other quadrants, the sign of the dE and dN would change. In all instances, the quadrant in which the traverse leg lies determines when dE and dN will be added to or subtracted from coordinates of Station A (fig 9–12).

9–14. Determination of dH

a. In a traverse, the field artillery surveyor is required to determine the height of each of the

unknown stations in relation to the height of the starting (known) station. This is accomplished by computing the difference in height (dh) between the occupied and the forward station. The vertical angle at the occupied station and the horizontal measured distance to the forward station are used to determine the difference in height between the two stations through the solution of a right triangle. This difference is then added to or subtracted from the known height at the occupied station.

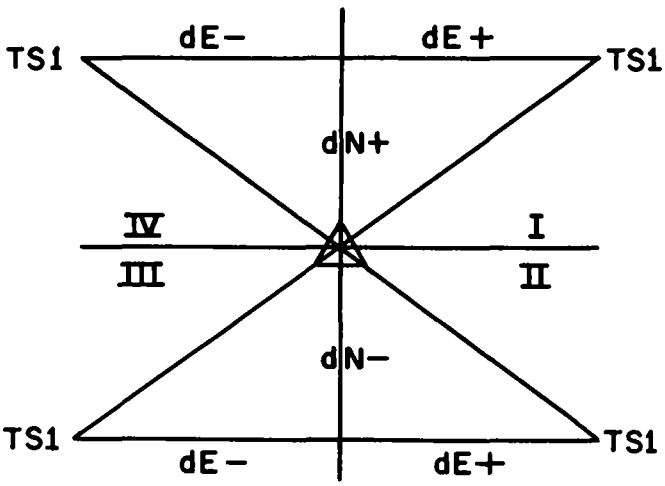


Figure 9–12. Quadrant-sign relationship for dE and dN.

b. In figure 9–13, the distance is the horizontal measured distance from Station A to Station B. The vertical angle at Station A is measured to the height of instrument (HI) at Station B. AA′ is the height of instrument at Station A and BB′ is the height of instrument at Station B. Both of the heights are the distances from the known ground elevation at Station A to the horizontal axis of the telescope of the instrument being used. AA′ is equal to BB′. The height of instrument must be determined and marked on the range pole at the forward station. The difference in height (dH) between the two stations is that side of the right triangle which requires solving.

To determine dH:

$$\text{Tangent of vertical angle} = \frac{\text{opposite side}}{\text{adjacent side}} = \frac{\text{dH}}{\text{distance}}$$

or,

dH = tangent of vertical angle X distance.

The dH computed is actually the difference in height at ground level between the two stations.

Note. The computed dH will be added or subtracted from the height of the known station according to the sign of the measured vertical angle.

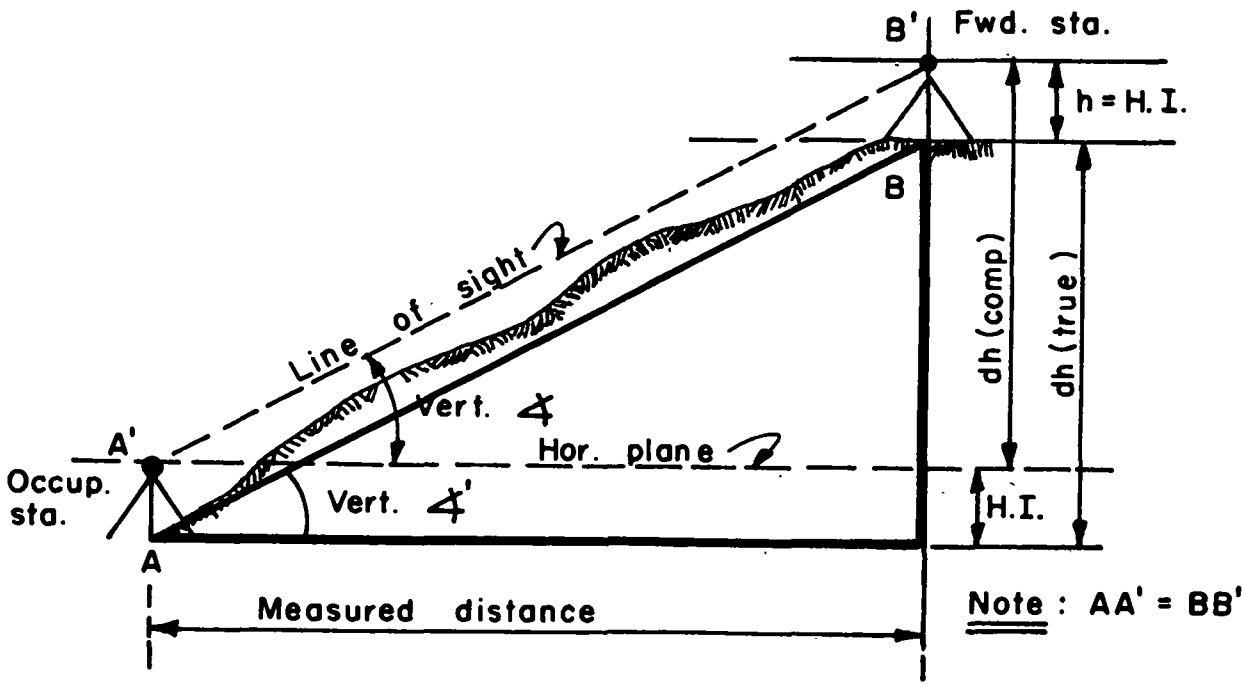


Figure 9–13. Right triangle for determination of dH.

TABLE-UTM GRID SCALE FACTORS FOR ARTILLERY

Add log scale factor to log ground distance to obtain log UTM grid distance. The easting value used to determine log UTM scale factor is easting of the known station to nearest 10,000 meters.

EASTING OF STARTING STATION		LOG SCALE FACTOR
500,000	500,000	9.9998300
490,000	510,000	9.9998300
480,000	520,000	9.9998300
470,000	530,000	9.9998300
460,000	540,000	9.9998300
450,000	550,000	9.9998400
440,000	560,000	9.9998400
430,000	570,000	9.9998500
420,000	580,000	9.9998600
410,000	590,000	9.9998700
400,000	600,000	9.9998800
390,000	610,000	9.9998900
380,000	620,000	9.9999000
370,000	630,000	9.9999200
360,000	640,000	9.9999300
350,000	650,000	9.9999500
340,000	660,000	9.9999700
330,000	670,000	9.9999800
320,000	680,000	0.0000000
310,000	690,000	0.0000200
300,000	700,000	0.0000400
290,000	710,000	0.0000600
280,000	720,000	0.0000900
270,000	730,000	0.0001100
260,000	740,000	0.0001300
250,000	750,000	0.0001600
240,000	760,000	0.0001900
230,000	770,000	0.0002200
220,000	780,000	0.0002500
210,000	790,000	0.0002800
200,000	800,000	0.0003100
190,000	810,000	0.0003400
180,000	820,000	0.0003700
170,000	830,000	0.0004100
160,000	840,000	0.0004500
150,000	850,000	0.0004800
140,000	860,000	0.0005200
130,000	870,000	0.0005600
120,000	880,000	0.0006000
110,000	890,000	0.0006400
100,000	900,000	0.0006900

GIVEN:
Coordinates and Height of occupied station.
Azimuth STATION to REAR STATION.

FIELD DATA:
Observe horizontal angles and vertical angles.
Tape horizontal ground distance between occupied station and forward station.

GUIDE:
Enter field data in blocks marked.
Sign of dH; (+) when elevation angle, (-) when depression angle.

LIMITATIONS:
This form should not be used for vertical control when horizontal distance exceeds 1,000 meters unless reciprocal vertical angles are observed and meaned.
This computation requires that HI at occupied station and height of target at forward station be equal.
When distance exceeds 1,000 meters or when HI and height of target are unequal use DA Form 6-2B for more accurate vertical control.

RESULTS:
Coordinates and height of forward station.

FORMULA:
dE = dist. x Sin Bearing dN = dist. x Cos Bearing dH = dist. x tan vertical angle.

* U.S. GOVERNMENT PRINTING OFFICE : 1963 O - 634263

Figure 9–14. DA Form 6–2 (back).

9–15. Scale Factor

The purpose of the log scale factor is to convert ground distance to map distance when the Universal Transverse Mercator (UTM) grid system is used. The log of the scale factor is applied to the dE and dN computations of all surveys executed to a fourth-order accuracy.

This factor is not used in surveys performed to accuracies of less than fourth-order. The scale factor will vary with the distance of the occupied station from the central meridian of the UTM grid zone. Scale factors are given for every 10,000 meters east and west of the central meridian and are shown in tabulated form on the back of DA Form 6–2 (Computation—Coordinates and Height From Azimuth, Distance and Vertical Angle). The log values of the scale factor are extracted by entering the table (fig 9–14) with the approximate easting value of the occupied station to the nearest 10,000 meters. When distances between stations exceed 5,000 meters in easting, the scale factor used is for the approximate midpoint of the line rather than that for the occupied station.

Section III. COMPUTATIONS

9–16. Purpose of DA Computational Forms

Survey computations can be performed in any mathematical sequence which will produce the correct solution. However, for the purpose of simplicity and uniformity, the Department of the Army has devised standardized forms for use in making survey computations. Accurate and timely computations are the key to a successful survey. Computations performed on a standard form are easily checked, corrected, adjusted, and filed when necessary.

9–17. DA Form 6–2

a. DA Form 6–2 is the form on which traverses are computed. It is used to determine coordinates and height from azimuth, distance and vertical angle.

b. Entries on the form are as shown in figures 9–15 and 9–16. Figure 9–15 is a sample computation showing a portion of a fifth-order survey computed using TM6–230 (6-place Logarithmic Tables). A scale factor was not used. Figure 9–16 is a sample computation showing a portion of a fourth-order survey using TM6–231 (7-place Logarithmic Tables). A scale factor is used for all fourth-order surveys.

c. Formulas to be used are those discussed in paragraphs 9–13 and 9–14 and are shown on the back of DA Form 6–2 (see fig 9–14).

9–18. Reciprocal Measurement of Vertical Angles

The effects of the curvature of the earth and atmospheric refraction must be considered for traverse legs in excess of 1,000 meters. These effects can be compensated for by reciprocal measurement at each end of such a leg. When vertical angles are measured reciprocally, the vertical angle at each end of the leg should be measured to the same height above the station (normally HI). If this cannot be done, DA Form 6–2b (Computation—Trigonometric Heights) must be used in computing the height of the forward station.

9–19. DA Form 6–2b

a. DA Form 6–2b (fig 9–17) is used to determine the height of the forward station when the vertical angles are measured reciprocally or nonreciprocally to different heights above the station.

b. Entries required to compute the form are the measured vertical angles, height of occupied station, height of instrument, height of target, and UTM grid or horizontal ground distance in meters between stations.

c. The formula to be used is shown on the back of DA Form 6–2b (fig 9–18).

9–20. DA Form 6–1

a. In survey operations, it is frequently necessary to determine the azimuth and distance between two stations of known coordinates. Some examples of such a requirement are the computation of azimuth and length of a target area base, the base of a triangulation scheme, computation of azimuth and distance between critical points when converting an assumed grid to a common grid, and the computation of a starting azimuth for a control point when the coordinates of the two intervisible points are known. The standardized form for this computation is DA Form 6–1.

b. The procedure for computing azimuth and

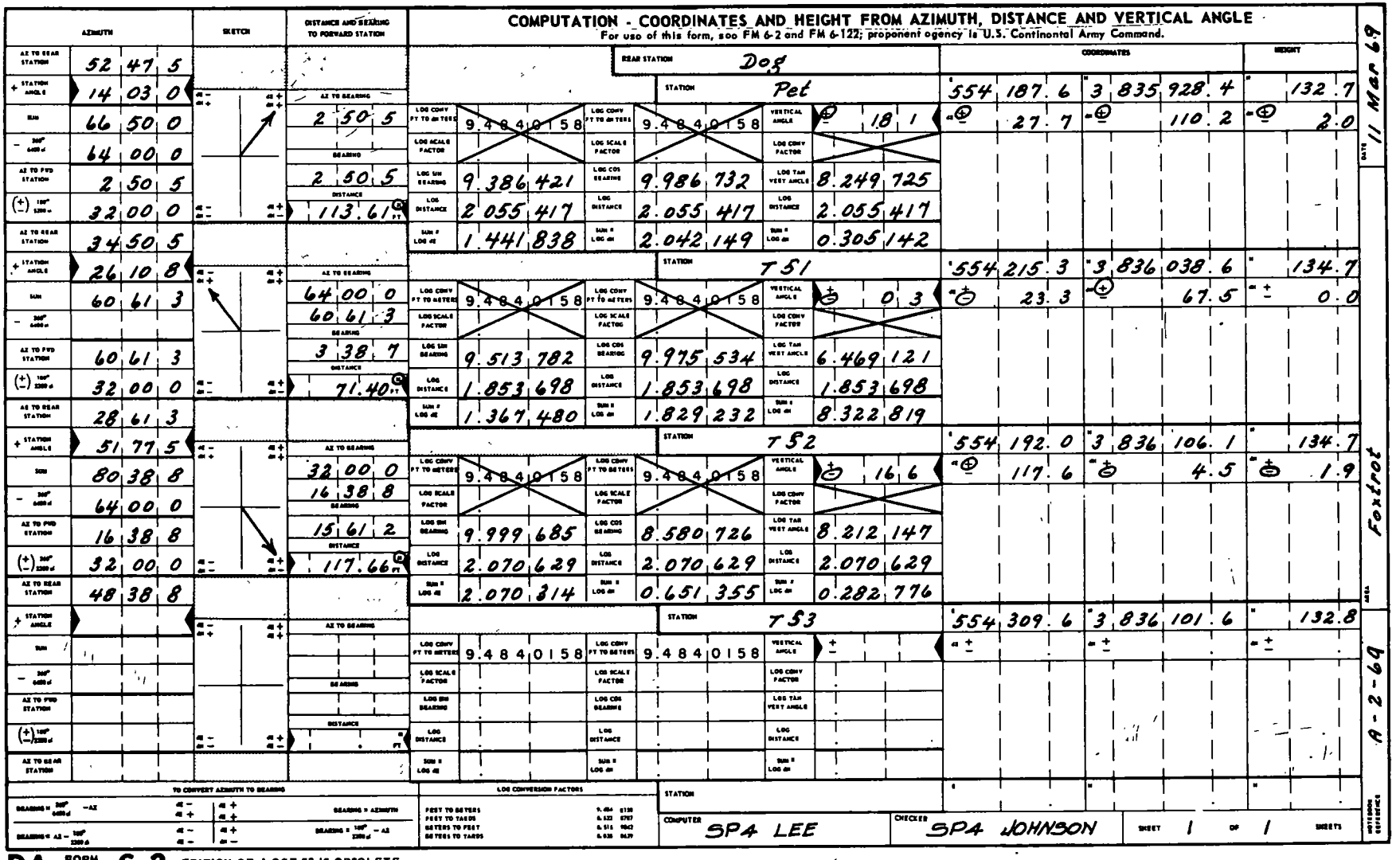
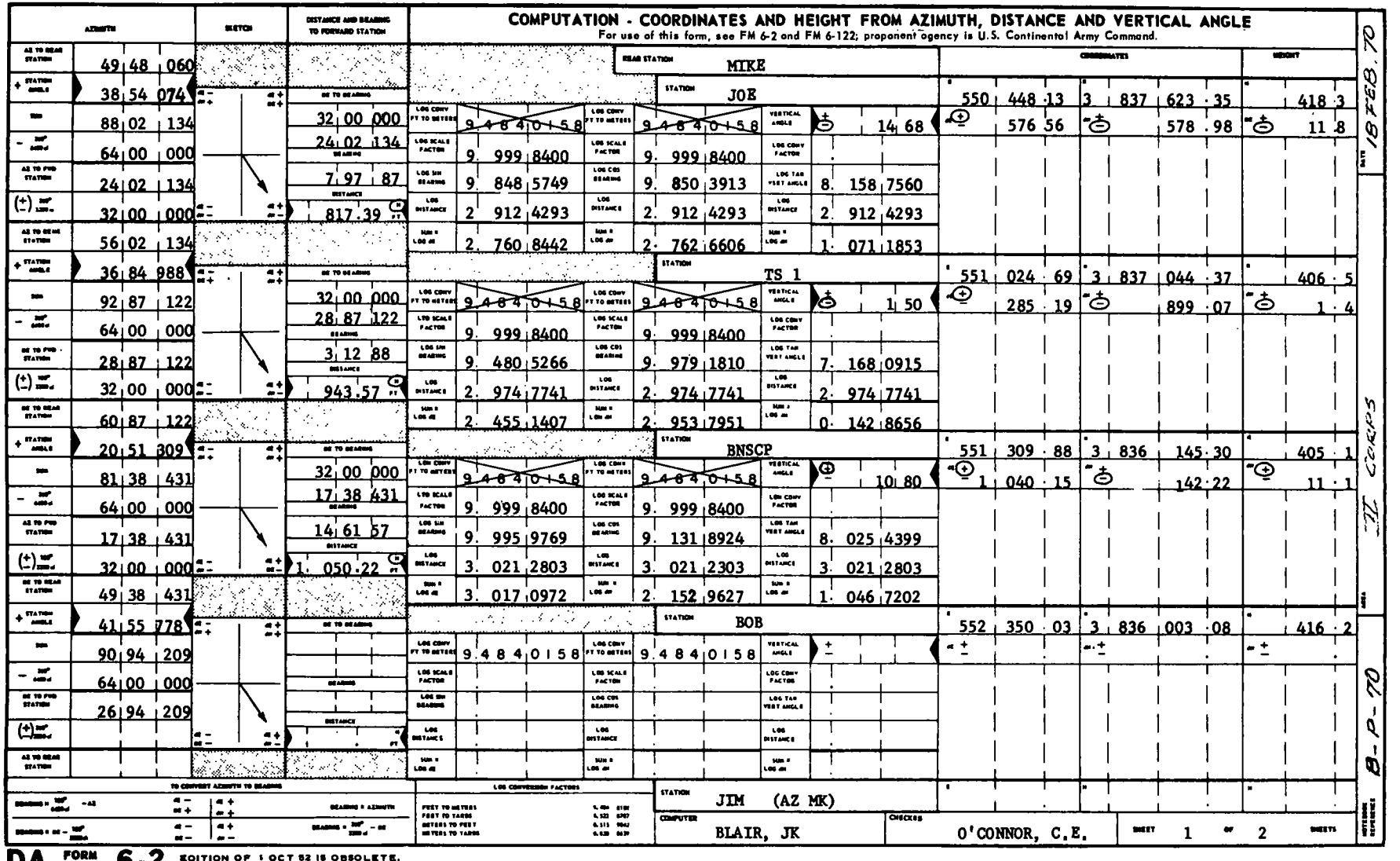


Figure 9–15. Sample form computation of illustrative traverse (fifth order).



COMPUTATION - COORDINATES AND HEIGHT FROM AZIMUTH, DISTANCE AND VERTICAL ANGLE

For use of this form, see FM 6-2 and FM 6-122; proponent agency is U.S. Continental Army Command.

AZIMUTH	SKETCH	DISTANCE AND BEARING TO FORWARD STATION	REAR STATION / STATION	COORDINATES	HEIGHT
AZ TO REAR STATION 49 48 060			REAR STATION MIKE		
+ STATION ANGLE 38 54 074		BE TO BEARING 32 00 000	STATION JOE	550 448.13 / 3 837 623.35	418.3
SUM 88 02 134		BEARING 24 02 134	LOG CONV FT TO METERS 9.484 0158 / 9.484 0158 / VERTICAL ANGLE ± 14 68	± 576.56 / ± 578.98	± 11.8
− 180° 64 00 000		DISTANCE 7 97 87	LOG SCALE FACTOR 9.999 8400 / 9.999 8400 / LOG CONV FACTOR		
AZ TO FWD STATION 24 02 134		DISTANCE 817.39 FT	LOG SIN BEARING 9.848 5749 / LOG COS BEARING 9.850 3913 / LOG TAN VERT ANGLE 8.158 7560		
(±) 180° 32 00 000			LOG DISTANCE 2.912 4293 / 2.912 4293 / 2.912 4293		
AZ TO REAR STATION 56 02 134			SUM = LOG dE 2.760 8442 / SUM = LOG dN 2.762 6606 / 1.071 1853		
+ STATION ANGLE 36 84 988		BE TO BEARING 32 00 000	STATION TS 1	551 024.69 / 3 837 044.37	406.5
SUM 92 87 122		BEARING 28 87 122	LOG CONV FT TO METERS 9.484 0158 / 9.484 0158 / VERTICAL ANGLE ± 1 50	± 285.19 / ± 899.07	± 1.4
− 180° 64 00 000		DISTANCE 3 12 88	LOG SCALE FACTOR 9.999 8400 / 9.999 8400 / LOG CONV FACTOR		
BE TO FWD STATION 28 87 122		DISTANCE 943.57 FT	LOG SIN BEARING 9.480 5266 / LOG COS BEARING 9.979 1810 / LOG TAN VERT ANGLE 7.168 0915		
(±) 180° 32 00 000			LOG DISTANCE 2.974 7741 / 2.974 7741 / 2.974 7741		
BE TO REAR STATION 60 87 122			SUM = LOG dE 2.455 1407 / SUM = LOG dN 2.953 7951 / 0.142 8656		
+ STATION ANGLE 20 51 309		BE TO BEARING 32 00 000	STATION BNSCP	551 309.88 / 3 836 145.30	405.1
SUM 81 38 431		BEARING 17 38 431	LOG CONV FT TO METERS 9.484 0158 / 9.484 0158 / VERTICAL ANGLE ± 10 80	± 1 040.15 / ± 142.22	± 11.1
− 180° 64 00 000		DISTANCE 14 61 57	LOG SCALE FACTOR 9.999 8400 / 9.999 8400 / LOG CONV FACTOR		
AZ TO FWD STATION 17 38 431		DISTANCE 1 050.22 FT	LOG SIN BEARING 9.995 9769 / LOG COS BEARING 9.131 8924 / LOG TAN VERT ANGLE 8.025 4399		
(±) 180° 32 00 000			LOG DISTANCE 3.021 2803 / 3.021 2303 / 3.021 2803		
BE TO REAR STATION 49 38 431			SUM = LOG dE 3.017 0972 / SUM = LOG dN 2.152 9627 / 1.046 7202		
+ STATION ANGLE 41 55 778		BE TO BEARING	STATION BOB	552 350.03 / 3 836 003.08	416.2
SUM 90 94 209		BEARING	LOG CONV FT TO METERS 9.484 0158 / 9.484 0158 / VERTICAL ANGLE ±	± / ±	±
− 180° 64 00 000		DISTANCE	LOG SCALE FACTOR / / LOG CONV FACTOR		
BE TO FWD STATION 26 94 209		DISTANCE FT	LOG SIN BEARING / LOG COS BEARING / LOG TAN VERT ANGLE		
(±) 180°			LOG DISTANCE / /		
AZ TO REAR STATION			SUM = LOG dE / SUM = LOG dN /		

TO CONVERT AZIMUTH TO BEARING

LOG CONVERSION FACTORS

FEET TO METERS	9.484 0158
FEET TO YARDS	9.522 8797
METERS TO FEET	0.515 9842
METERS TO YARDS	0.539 3639

STATION JIM (AZ MK)

COMPUTER BLAIR, JK

CHECKED O'CONNOR, C.E.

SHEET 1 OF 2 SHEETS

DATE 18 FEB 70

AREA III CORPS

8-P-70

DA FORM 1 AUG 55 6-2 EDITION OF 1 OCT 52 IS OBSOLETE.

Figure 9–16. Sample form computation of illustrative traverse (fourth order).

COMPUTATION—TRIGONOMETERIC HEIGHTS

		OCCUPIED STATION	SCP 2	SCP 3		
		FORWARD STATION	SCP 3	SCP 4		
		HORIZONTAL DISTANCE BETWEEN STATIONS — GROUND ☐ UTM GRID ☒	8 693.82	3 426.39		
BLOCK I	1	HEIGHT OF INSTRUMENT AT OCCUPIED STATION	+ 1.6	+ 1.6	+	+
	2	HEIGHT OF TARGET AT FORWARD STATION	− 1.6	− 1.6	−	−
	3	ALGEBRAIC SUM (1) AND (2)	± 0.0	± 0.0	±	±
RECIPROCAL ANGLES ONLY BLOCK II	4	HEIGHT OF INSTRUMENT AT FORWARD STATION	− 1.6	− 1.6	−	−
	5	ALGEBRAIC SUM (3) AND (4)	⊖ 1.6	⊖ 1.6	±	±
	6	HEIGHT OF TARGET AT OCCUPIED STATION	+ 1.6	+ 1.6	+	+
	7	ALGEBRAIC SUM (5) AND (6)	± 0.0	± 0.0	±	±
	8	1/2 OF (7)	± 0.0	± 0.0	±	±
	9	VERTICAL ANGLE OCCUPIED STATION TO FORWARD STATION	⊕ 18 90	⊖ 10 30	±	±
	10	VERTICAL ANGLE FORWARD STATION TO OCCUPIED STATION WITH SIGN REVERSED	⊕ 18 93	⊖ 10 34	±	±
	11	ALGEBRAIC SUM (9) AND (10)	⊕ 37 83	⊖ 20 64	±	±
	12	1/2 OF (11)	⊕ 18 92	⊖ 10 32	±	±
BLOCK III		NON-RECIPROCAL ANGLES ONLY				
	12	VERTICAL ANGLE OCCUPIED STATION TO FORWARD STATION	±	±	±	±
BLOCK IV	13	LOG OF HORIZONTAL DISTANCE BETWEEN STATIONS	3.939 2106	3.534 8368		
	14	LOG TAN (12)	8.268 9710	8.005 6945		
	15	(13)+(14)	2.208 1816	1.540 5313		
	16	IF HORIZONTAL DISTANCE IS: GRID, USE LOG SCALE FACTOR FROM REVERSE; GROUND, LEAVE BLANK	9.999 8400	9.999 8400		
	17	(15)−(16)	2.208 3416	1.540 6913		
	18	NUMBER HAVING LOG (17) USE SIGN OF (12)	⊕ 161.6	⊖ 34.7	±	±
	19	IF BLOCK II IS BLANK REPEAT (3) IF BLOCK II IS FILLED REPEAT (8)	± 0.0	± 0.0	±	±
	20	ALGEBRAIC SUM (18) AND (19)	⊕ 161.6	⊖ 34.7	±	±
	21	NON-RECIPROCAL ANGLES ONLY: CURVATURE AND REFRACTION CORRECTION FROM REVERSE	+	+	+	+
	22	ALGEBRAIC SUM (20) AND (21)	⊕ 161.6	⊖ 34.7	±	±
	23	HEIGHT OF ☒ OCCUPIED ☐ FORWARD STATION	+ 371.6	+ 533.2	+	+
	24	IF (23) IS HEIGHT OF OCCUPIED STATION REPEAT (22); IF (23) IS HEIGHT OF FORWARD STATION REPEAT (22) WITH OPPOSITE SIGN	⊕ 161.6	⊖ 34.7	±	±
	25	ALGEBRAIC SUM (23) AND (24) = HEIGHT OF ☐ OCCUPIED ☒ FORWARD STATION	533.2	498.5		

COMPUTER: BRAUN | CHECKER: HOFELDT | SHEET 1 OF 1 SHEETS

NOTEBOOK REFERENCE: 1-16 | AREA: FOXTROT | DATE: 16 JAN 69

DA FORM 1 MAY 56 6-2b REPLACES DA FORM 6-2b, 1 OCT 52, WHICH IS OBSOLETE.

Figure 9–17. Computation of height, fourth-order survey.

TABLE - CORRECTION FOR CURVATURE AND REFRACTION
(No interpolation necessary for Artillery Survey)
Use only when dH is computed using non-reciprocal vertical angles.
SIGN ALWAYS PLUS
Enter in (21)

Log Dist (M)	Corr (M)
3.079	.1
3.230	.2
3.322	.3
3.386	.4
3.435	.5
3.473	.6
3.508	.7
3.537	.8
3.562	.9
3.584	1.0
3.625	1.2
3.658	1.4
3.687	1.6
3.712	1.8
3.736	2.0
3.784	2.5
3.824	3.0
3.857	3.5
3.886	4.0
3.912	4.5
3.934	5.0
3.955	5.5
3.974	6.0
3.992	6.5
4.007	7.0

TABLE-UTM GRID SCALE FACTORS FOR ARTILLERY

EASTING OF STARTING STATION		LOG SCALE FACTOR
500,000	500,000	9.9998300
490,000	510,000	9.9998300
480,000	520,000	9.9998300
470,000	530,000	9.9998300
460,000	540,000	9.9998300
450,000	550,000	9.9998400
440,000	560,000	9.9998400
430,000	570,000	9.9998500
420,000	580,000	9.9998600
410,000	590,000	9.9998700
400,000	600,000	9.9998800
390,000	610,000	9.9998900
380,000	620,000	9.9999000
370,000	630,000	9.9999200
360,000	640,000	9.9999300
350,000	650,000	9.9999500
340,000	660,000	9.9999700
330,000	670,000	9.9999800
320,000	680,000	0.0000000
310,000	690,000	0.0000200
300,000	700,000	0.0000400
290,000	710,000	0.0000600
280,000	720,000	0.0000900
270,000	730,000	0.0001100
260,000	740,000	0.0001300
250,000	750,000	0.0001600
240,000	760,000	0.0001900
230,000	770,000	0.0002200
220,000	780,000	0.0002500
210,000	790,000	0.0002800
200,000	800,000	0.0003100
190,000	810,000	0.0003400
180,000	820,000	0.0003700
170,000	830,000	0.0004100
160,000	840,000	0.0004500
150,000	850,000	0.0004800
140,000	660,000	0.0005200
130,000	870,000	0.0005600
120,000	880,000	0.0006000
110,000	890,000	0.0008400
100,000	900,000	0.0006900

Given:
UTM grid distance or horizontal ground distance in meters between stations.
Height of one station in meters.

Field data:
Observe vertical angle between instrument at one station and target at other station.
Height of instrument.
Height of target.

Guide:
Enter field data in blocks marked [redacted].
When vertical angles are observed in two directions, either station may be designated as the occupied station. Use Blocks I, II, and IV.
When vertical angle is observed in one direction, use Blocks I, III, and IV. Use curvature and refraction correction from table above.
Elevation of occupied station need not be known.
In (16), obtain approximate easting coordinate of occupied station from other computations or from map. Use this value to obtain scale factor from table above.
If height of either station in (23) is below sea level (-), add 1,000 meters algebraically to (23); proceed with computation as indicated. Subtract 1,000 meters algebraically from (25) to obtain height of station.
If height of occupied station is used in (23), then height of forward station is obtained in (25).
All angular units used in computation must be the same (mils or degrees).

Limitation:
This computation does not provide for reduction of ground distance to sea level distance.

Results:
Height of the unknown station in meters.

GOVERNMENT PRINTING OFFICE · 1956 O—385533

Figure 9–18. Back of DA Form 6–2b.

☆ U. S. GOVERNMENT PRINTING OFFICE: 1955 O—355492

COMPUTATION - AZIMUTH AND DISTANCE FROM COORDINATES

For use of this form, see FM 6-2 and FM 6-122; proponent agency is U.S. Continental Army Command.

STATION		E COORDINATE		N COORDINATE
FROM: Pet	A	554 187 . 6	A	3 835 928 . 4
TO: Dog	B	553 864 . 2	B	3 836 080 . 3
IF A IS LESS THAN B, REPEAT A	AA		AA	3 835 928 . 4
IF AA IS BLANK, USE A-B, SIGN (−) IF AA IS FILLED, USE B-AA, SIGN (+)	dE	(−) 323 . 4	dN	(+) 151 . 9

AZ. = 360°/6400 mil − Bearing (dE −, dN +) | AZ. = Bearing (dE +, dN +)

AZ. = 180°/3200 mil + Bearing (dE −, dN −) | AZ. = 180°/3200 mil − Bearing (dE +, dN −)

LOG dE	2 . 509 740	ANGLE HAVING LOG TAN BEARING A TO B	11 52 7
LOG dN	2 . 181 558	DETERMINE AZIMUTH FROM BEARING BY PLOTTING dE AND dN ON SKETCH AND USING SKETCH AS GUIDE	64 00 0
LOG dE − LOG dN = LOG TAN BEARING A TO B	0 . 328 182		11 52 7
		AZIMUTH A TO B	52 47 3

IF dE IS MORE THAN dN		IF dE IS LESS THAN dN	
REPEAT LOG dE	2 . 509 740	REPEAT LOG dN	
LOG SIN BEARING	9 . 956 706	LOG COS BEARING	
LOG dE − LOG SIN BEARING = LOG GRID DISTANCE A TO B IN METERS	2 . 553 034	LOG dN − LOG COS BEARING = LOG GRID DISTANCE A TO B IN METERS	
LOG CONVERSION FACTOR METERS TO YARDS	0.0 3 8 8 6 2 9	LOG CONVERSION FACTOR METERS TO YARDS	0.0 3 8 8 6 2 9
LOG GRID DIST IN M + LOG CONV FACTOR = LOG GRID DISTANCE A TO B IN YARDS		LOG GRID DIST IN M + LOG CONV FACTOR = LOG GRID DISTANCE A TO B IN YARDS	
	357 . 3 (M) YDS		M YDS

STATION		E COORDINATE		N COORDINATE
FROM.	A		A	
TO.	B		B	
IF A IS LESS THAN B, REPEAT A	AA		AA	
IF AA IS BLANK, USE A-B, SIGN (−) IF AA IS FILLED, USE B-AA, SIGN (+)	dE	+ / −	dN	+ / −

AZ. = 360°/6400 mil − Bearing (dE −, dN +) | AZ. = Bearing (dE +, dN +)

AZ. = 180°/3200 mil + Bearing (dE −, dN −) | AZ. = 180°/3200 mil − Bearing (dE +, dN −)

LOG dE		ANGLE HAVING LOG TAN BEARING A TO B	
LOG dN		DETERMINE AZIMUTH FROM BEARING BY PLOTTING dE AND dN ON SKETCH AND USING SKETCH AS GUIDE	
LOG dE − LOG dN = LOG TAN BEARING A TO B			
		AZIMUTH A TO B	

IF dE IS MORE THAN dN		IF dE IS LESS THAN dN	
REPEAT LOG dE		REPEAT LOG dN	
LOG SIN BEARING		LOG COS BEARING	
LOG dE − LOG SIN BEARING = LOG GRID DISTANCE A TO B IN METERS		LOG dN − LOG COS BEARING = LOG GRID DISTANCE A TO B IN METERS	
LOG CONVERSION FACTOR METERS TO YARDS	0.0 3 8 8 6 2 9	LOG CONVERSION FACTOR METERS TO YARDS	0.0 3 8 8 6 2 9
LOG GRID DIST IN M + LOG CONV FACTOR = LOG GRID DISTANCE A TO B IN YARDS		LOG GRID DIST IN M + LOG CONV FACTOR = LOG GRID DISTANCE A TO B IN YARDS	
	M YDS		M YDS

FORMULAS

$\text{TAN BEARING} = \frac{dE}{dN}$ ° GRID DISTANCE = $\frac{dE}{\text{SIN BEARING}} = \frac{dN}{\text{COS BEARING}}$

COMPUTER	CHECKER	SHEET	OF	SHEETS
NESMITH	SHULTZ	1	1	

NOTEBOOK REFERENCE	AREA	DATE
B-37	Ft. Sill	16 Jan 67

DA FORM 1 AUG 55 6-1 REPLACES EDITION OF 1 NOV 53, WHICH WILL BE USED UNTIL EXHAUSTED.

Figure 9–19. Sample computation, DA Form 6–1.

distance from coordinates is the reverse of the procedure for computing coordinates from azimuth and distance.

c. The procedure involved can best be explained by using an illustration of a right triangle. In figure 9–12, A and TS1 are points of known coordinates. The two points, the intersection of the grid easting line through one of the points (TS1), and the grid northing line through the other point (Pt A) form a right angle. By extending a straight line between points A and TS1, a right triangle is formed. The side lengths of this triangle are determined by the algebraic difference in the easting coordinates (dE) of the two points, the algebraic difference in the northing coordinates (dN) of the two points, and the grid distance between the two points. The azimuth and distance from Point A to TS1 are desired. The signs (±) of dE and dN, as determined on the form (DA Form 6–1), are used for finding the quadrant in which the azimuth is located. The right triangle formed is used to determine the bearing angle of the desired azimuth as follows:

$$\text{Tangent of bearing angle} = \frac{\text{opposite side}}{\text{adjacent side}} = \frac{\text{dE}}{\text{dN}}$$

After the bearing angle is known, the azimuth can be determined using the sketch block in the upper right corner of the DA Form 6–1 in which dE and dN were plotted.

d. The bearing angle and side dE or side dN, whichever is larger, are the factors needed to compute the distance between the two points (the hypotenuse).

(1) $$\text{Sine of bearing angle} = \frac{\text{opposite side}}{\text{hypotenuse}} = \frac{\text{dE}}{\text{grid distance}}$$

(2) $$\text{Cosine of bearing angle} = \frac{\text{adjacent side}}{\text{hypotenuse}} = \frac{\text{dN}}{\text{grid distance}}$$

or,

(1) $$\text{Grid distance} = \frac{\text{dE}}{\text{Sine of Bearing Angle}}$$

(2) $$\text{Grid distance} = \frac{\text{dN}}{\text{Cosine of Bearing Angle}}$$

If dE is larger, the equation in (1) is used; if dN is larger, the equation in (2) is used. The larger side is used, since it is opposite the stronger angle in the right triangle (para 10–7*b*), thus enabling the determination of a more accurate distance. An example of a computation of azimuth and distance from coordinates on DA Form 6–1 is shown in figure 9–19.

9–21. Accuracy Ratio

a. Certain minimum accuracy requirements are prescribed for survey computations according to the use to be made of the survey data. To determine whether this accuracy requirement has been met for a closed traverse, an accuracy ratio is computed. If this accuracy requirement is not met and the errors cannot be determined, the traverse must be re-run.

b. An accuracy ratio is expressed as a ratio between the radial error of closure and the total length of the traverse (e.g., 1:3,000, 1:1,000). It may also be expressed as a fraction with a numerator of 1 (e.g., 1/3000, 1/1000). The *radial error of closure* is the linear distance between the correct coordinates of the closing station and the coordinates of the point as determined from the survey. The total length of the traverse is the sum of the lengths of all traverse legs (excluding distances to offset stations). The numerator of the accuracy ratio is 1; the denominator is equal to the total length of the traverse divided by the radial error of closure. The equation for the accuracy ratio is as follows:

$$\text{Accuracy Ratio} = \frac{1}{\text{Total length of traverse} \div \text{radial error of closure}}$$

c. After the accuracy ration has been computed, the denominator of the fraction is always reduced to the next lower hundred (e.g., 1/3879 becomes 1/3800).

9–22. Radial Error of Closure

a. To determine the radial error of closure, the correct coordinates of the closing point are compared with the computed coordinates of that point and the differences are determined. The difference between the two eastings of the closing point, easting error (eE), forms one side of a right triangle. The difference between the two northings of the closing point, northing error (eN), forms the second side of the triangle. The hypotenuse of this right triangle is the radial error of closure (fig 9–20). It is computed using DA Form 6–1 or the Pythagorean theorem. From the Pythagorean theorem, it is derived that the radial error of closure is equal to the square root of the sum of the

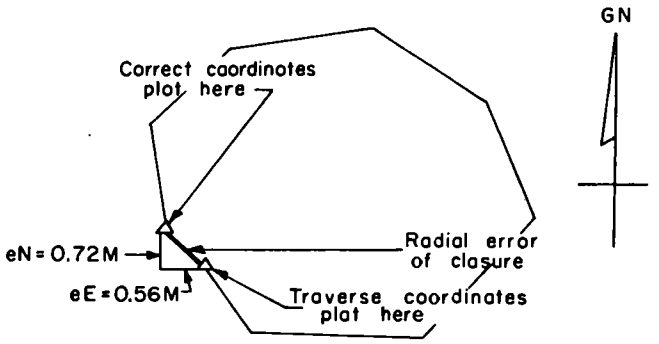


Figure 9-20. Radial error of closure.

square of the error in easting and the square of the error in northing. The equation for the computation of the radial error is as follows:

Radial error of closure =

$$\sqrt{(eE)^2 + (eN)^2}$$ where—

(1) Error in easting (eE) = difference in easting coordinates.

(2) Error in northing (eN) = difference in northing coordinates.

b. The maximum allowable error in position closure for a fourth-order traverse generally is expressed as 1:3,000 or 1 unit of radial error for each 3,000 similar units of traverse. A *maximum allowable radial error* for a fourth-order survey is determined in one of two ways. If the traverse is less than 9,000 meters in length, the *maximum* allowable radial error is determined by dividing the total length of the traverse by 3,000. For example, in a 3,469.91 meter, fourth-order traverse, the 1:3,000 evaluation is determined as follows:

```
          1.15  = maximum allowable radial error
3000) 3,469.91
       3,000
        4699
        3000
       16991
       15000
```

When the traverse length exceeds 9,000 (9K) meters, the accuracy achieved may be within 1:3,000 yet the radial error will be excessive.

Therefore the maximum allowable radial error is determined by the formula $AE = 1M\sqrt{K}$

Where AE = Allowable radial error,
M = meter,
K = total length of the traverse to the nearest one tenth kilometer. To illustrate the point, a traverse 37.3 kilometers in length, when using the 1:3,000 evaluation would allow a maximum radial error of 12.4 M.

```
          12.4 M
3000) 37,300.0
       30,000
        7,300
        6,000
        1,3000
        1,2000
```

Whereas $1M\sqrt{K}$ would allow a maximum radial error of 6.1 M.

```
          6.1 M
1M      37.30
          36
121       130
          130
```

The result of the method used, will then be compared with the radial error computed for the traverse (para 9-23), to determine if the traverse radial error meets the requirement. If the radial error of the traverse exceeds the computed maximum allowable radial error, the traverse must be re-run.

9-23. Example of Computing an Accuracy Ratio

An example of the method of computing the accuracy ratio for a closed fourth-order traverse of less than 9,000 meters in length is as follows:

Correct coordinates of closing point	=	555131.89	3839365.46
Traverse coordinates of closing point	=	555131.33	3839364.74
Errors of closure	eE =	0.56	eN = 0.72

Radial error = $\sqrt{(.56)^2 + (.72)^2} = \sqrt{.820} = 0.91$

The total length of the traverse is 3469.91 meters.

Accuracy ratio = $\frac{1}{3469.91 \div .91} = \frac{1}{3813} = \frac{1}{3800}$

9-24. Closing Azimuth Error

The closing azimuth error is determined by comparing the known closing azimuth with the closing azimuth determined by the traverse. The difference between the two is the closing azimuth error. The error is considered to be within tolerance if it does not exceed 0.5 mil per main scheme station angle for 1:500 traverse and 0.1 mil (20″) per main scheme station angle for fifth order traverse. Fourth-order traverses are evaluated for azimuth closure in two ways. If the number of main scheme angles is six or less, use 0.04 mil times the number of main scheme angles. For traverses of seven or more main scheme angles, use 0.1 times the square root of the number of main scheme angles (app B).

9–25. Accuracies, Specifications and Techniques

The overall accuracy of a traverse depends on the equipment and methods used in the measurements, the accuracy achieved during the fieldwork, and the accuracy of the starting and closing data. In artillery survey, three minimum accuracies serve as standards for survey personnel to meet both in fieldwork and in computations. These accuracies are fourth-order (1:3,000), fifth-order (1:1,000), and 1:500 survey (app H). Fourth-order surveys normally are performed by the corps artillery target acquisition battalion and by division artillery to extend and expand survey control. Field artillery battalions normally perform fifth-order surveys to establish survey control for the required elements of the battalion. Survey of 1:500 accuracy normally is performed only by artillery elements that have a limited survey capability (e.g., radar sections). The orders of survey are listed in appendix H. The specifications and techniques to achieve the accuracies required in artillery survey are tabulated in appendix B and are discussed in *a* through *c* below.

a. Fourth-Order Accuracy. Fourth-order surveys are normally performed by division artillery survey platoons and corps artillery acquisition battalions to extend survey control to using units. The maximum allowable error in position closure for an artillery fourth-order traverse is generally expressed as 1:3000, or 1 unit of radial error for each 3,000 similar units of traverse executed. A fourth-order traverse starting from existing survey control must start and close on stations established to an accuracy of fourth-order or higher. If survey control of the required accuracy is not available, the fieldwork and computations can be computed and the traverse evaluated for accuracy (accuracy ratio determined) by using assumed starting data, provided the traverse is terminated at the starting station. The 0.002 mil theodolite is used to measure the angles. Horizontal angles are measured one position; vertical readings are taken once with the telescope in the direct position and once with the telescope in the reverse position (1D/R). The vertical angle is then computed. If legs are greater than 1,000 meters in length, vertical readings must be observed reciprocally. Distances are double-taped to a comparative accuracy of 1:5,000 with the 30-meter steel tape, measured in both directions with the DME, or when tellurometers are used, 2 coarse and 4 fine sets of readings must be taken to determine the distance.

(1) *Position accuracy.* The procedure used to evaluate the position accuracy of a fourth-order traverse depends upon the length of the main scheme of the traverse. Traverses of less than 9,000 meters in main scheme length are evaluated by determining accuracy ratios as explained in paragraph 9–23. However, when the traverse length exceeds 9,000 meters, the accuracy achieved may be within 1:3000 yet the radial error will be excessive. Therefore, when the main scheme length of the traverse exceeds 9,000 meters (9K), the maximum allowable radial error (AE) is computed by the formula $AE = 1M\sqrt{K}$ where K is the total length of the traverse to the nearest one tenth kilometer and 1M represents one meter (para 9–22).

Example:

Total length of traverse is 14,823.24 M

$AE = 1M\sqrt{K}$

$AE = 1M\sqrt{14.8}$

Log 14.8 = 1.170262

½Log 14.8 = 0.585131

AE = 3.84 × 1M (3.847 rounded to 3.85)

AE = 3.85 M

Therefore, 3.85 M is the maximum allowable radial error for this traverse length. If the radial error of the traverse as computed using the Pythagorean theorum exceeds 3.85M, the traverse must be re-run.

(2) *Azimuth closure.* The allowable error in azimuth closure depends on the number of main-scheme angles used in carrying the azimuth through the traverse. The allowable azimuth error in mils for a traverse having no more than six main scheme angles is computed by the formula AE = 0.04m x N, where N is the number of main scheme angles. If there are more than six main-scheme angles in the traverse, the allowable azimuth error is computed by the formula $AE = 0.1m\sqrt{N}$.

(3) *Height accuracy.* The allowable error in meters for the height closure of a traverse of any length performed to fourth-order accuracy is also computed by the formula $AE = 1m\sqrt{K}$ where K is the total length of the traverse in kilometers.

b. Fifth-Order Accuracy. Field artillery battalions normally perform this order of survey to establish survey control for the firing units of the battalion. A fifth-order traverse starting from existing control must start and close on stations established to an accuracy of fifth-order or greater. When survey control of the required accuracy is

not available, the fieldwork and computations can be completed and the traverse evaluated for accuracy (accuracy ratio) by using assumed starting data, provided the traverse is closed on the starting station. The 0.2 mil theodolite is the instrument used to measure the angles. Horizontal angles are turned on position, with the 0.2 mil theodolite; vertical readings are observed once with the telescope in the direct position and once with the telescope in the reverse position (1D/R). The vertical angle is then computed. Distances are single-taped with the 30-meter steel tape and checked for gross errors by pacing or are measured with electronic distance-measuring equipment if it is required (specifications for fifth-order DME measurements are shown in app B).

(1) *Position accuracy.* The maximum allowable error in position closure is expressed by the accuracy ratio of 1:1,000 or 1 unit of error for each 1,000 similar units of traverse executed.

(2) *Height accuracy.* The maximum allowable error in height closure is ± 2 meters.

(3) *Azimuth closure.* The allowable error in azimuth closure is computed by the formula AE= 0.1m x N, when N is the number of main-scheme angles in the traverse.

c. 1:500 Survey. This type of survey normally is performed only by artillery elements having a limited survey capability. The specifications and techniques for a 1:500 survey are as follows:

(1) *Position.* The allowable error in position closure is 1:500.

(2) *Height.* Vertical readings are observed twice with the aiming circle. The mean value of the two readings should be within ± 0.5 mil of the first reading. If not, the angle must be re-determined. The allowable error in height closure is ± 2 meters.

(3) *Azimuth.* Horizontal readings are observed two repetitions with the aiming circle. The accumulated value is divided by 2 to determine the mean value, which must be within ± 0.5 mil of the first reading. The allowable error in azimuth closure is computed by the formula AE = 0.5m x N, where N is the number of angles in the traverse.

Section IV. TRAVERSE ADJUSTMENT

9-26. General

Establishing a common grid throughout an entire corps or division artillery sector is not as simple as it may at first appear. When a party is extending survey control over long distances by traverse, the traverse may well be within the prescribed accuracy and still be considerably in error. This problem is magnified when several traverse parties are employed to extend control and attempt to tie their work together. Seldom, if ever, will these parties coincide on their linkage; but by adjusting the traverse throughout, some compensation will be made for those errors which have accumulated. A traverse executed to a prescribed accuracy of fourth-order must always be closed and adjusted. An adjusted traverse is one in which the errors have been distributed systematically so that the closing data as determined by the traverse coincides with the correct closing data. There is, of course, no possible means of determining the true magnitude of the errors in angle and distance measuring which occur throughout a traverse. Therefore, traverse adjustment is based on the assumption that the errors have gradually accumulated, and the corrections are made accordingly. Three adjustments must be made in adjusting a traverse—azimuth, coordinates and height. These adjustments eliminate the effects of systematic errors on the assumption that they have been constant and equal in their effect upon each traverse leg. Blunders, such as dropped tape lengths or misread angles, cannot be compensated for in traverse adjustment. Additionally, a traverse which does not meet the prescribed standard of accuracy is not adjusted but is checked for error. If the error cannot be found, the traverse must be performed again in its entirety.

9-27. Sources of Errors

The errors that are compensated for by traverse adjustment are not those errors commonly known as mistakes or blunders but are errors that fall into one of the following classes:

a. Instrumental Errors. Errors that arise from imperfections in, or faulty adjustment of, the instruments with which the measurements are taken. For example, a tape may be too long or the optical plumb may be out of adjustment.

b. Personnel Errors. Errors that arise from the limitations of the human senses of sight and touch. For example, an error may be made in esti-

mating the tension applied to a steel tape or plumbing a plumb bob over a point.

c. Natural Errors. Errors that arise from variations in the phenomena of nature, such as temperature, humidity, wind, gravity, refraction, and magnetic declination. For example, the length of a tape will vary directly with the temperature; i.e., it will become longer as the temperature increases and shorter as the temperature decreases.

9–28. Azimuth Adjustment

a. Determining Azimuth Correction. Since the computation of position is in part dependent on azimuth, the first step in adjusting a traverse is to determine the azimuth error and adjust the azimuth. The azimuth error is obtained by determining the difference between the azimuth established by traverse (computed) and the known azimuth at the closing point. The azimuth correction is the azimuth error with the proper sign affixed, so that the computed azimuth with the azimuth correction applied will equal the known azimuth. For example, a traverse is performed from Point "A" to Point "B". An azimuth from Point "A" to a visible azimuth mark was known to be 2,571.624 m, and was used as the starting azimuth. An azimuth from Point "B" to a different azimuth mark was known to be 4,794.529 m, and was used as the closing azimuth; however, the azimuth to the same point from Point "B" as derived from the traverse was found to be 4,794.459 mils. The azimuth correction for this traverse was found to be 0.070 mils. The azimuth correction for this traverse is determined as follows:

Azimuth error = known azimuth — azimuth established by traverse

Known azimuth	=	4794.529 mils
Computed azimuth	=	—4794.459 mils
Azimuth correction	=	+ .070 mils

b. Application of Azimuth Correction. Since traverse adjustment is based on the assumption that errors present have accumulated gradually and systematically throughout the traverse, the azimuth correction is applied accordingly. The correction is distributed equally among the angles of the traverse with any remainder distributed to the larger angles. For example, assume that the traverse for which the azimuth correction was determined consisted of three traverse legs and four angles as follows:

Traverse Leg	*Measured Angle*	
Pt "A'	2,410.716 mils	Ak Mk—Pt "A"—TS1
TS1	2,759.630 mils	Pt "A"—TS1—TS2
TS2	3,765.876 mils	TS1—TS2—Pt "B"
Pt "B'	2,886.617 mils	TS2—Pt "B" = Az Mk

The azimuth correction is divided by the total number of angles. In this case +0.070 mil ÷ 4 = 0.017 mil per angle with a remainder of 0.002 mil. Each of the four angles will be adjusted by 0.017 mil and the two largest angles will be adjusted by an additional 0.001 mil each to compensate for the remaining 0.002 mil.

Station	*Measured Angle*	*Azimuth Correction*	*Adjusted Angle*
Pt "A"	2,410.716	+0.017	2,410.733
TS1	2,759.630	+0.017	2,759.647
TS2	3,765.876	+0.018	3,765.894
Pt "B"	2,886.617	+0.018	2,886.635

c. Action After Adjustment. After the angles have been adjusted, the adjusted azimuth of each leg of the traverse should be computed by using the starting azimuth and the adjusted angles at each traverse station. These computations should be performed on fresh copies of DA Form 6–2, not on the sheets used in the original computations. The adjusted azimuth should be computed throughout the entire traverse and checked against the correct azimuth to the closing azimuth mark before any of the coordinate adjustments are begun.

9–29. Coordinate Adjustment

After the azimuth of each traverse leg has been adjusted, the coordinates of the stations in the traverse must be adjusted. The first step in adjusting the coordinates is to recompute the coordinates of all stations in the traverse, using the adjusted azimuths to obtain new bearing angles.

a. Determining Easting and Northing Corrections. The easting and northing corrections for the traverse are determined by subtracting the coordinates of the closing station (as recomputed with the adjusted azimuth) from the known coordinates of the closing station.

For example—

Correction = known coordinates — coordinates established by traverse

	E.	N.	
=	550554.50	—3835829.35	(correct coordinates)
—	550550.50	—3835835.35	(traverse coordinates)
=	eE +4.00	eN —6.00	

b. Application of Easting and Northing Corrections. The corrections determined in *a* above are for an entire traverse. The assumption is made that these corrections are based on errors proportionately accumulated throughout the traverse. Therefore, the corrections must be distributed proportionately throughout the traverse. The amount of easting or northing correction to be applied to the coordinates of each station is com-

puted by multiplying the total correction (easting or northing) by the total length of all the traverse legs up to that station and dividing the quotient by the total length of all of the legs in the traverse. For example, using the total easting and northing corrections previously determined, assume that the total length of the traverse is 22,216.89 meters and that the total length of the traverse legs up to TS4 is 3,846.35 meters.

Easting correction at TS4 =

$$\frac{\text{total easting correction} \times \text{traverse length to TS4}}{\text{total traverse length}}$$

$$= \frac{+4.00 \times 3{,}846.35}{22{,}216.89}$$

= + 0.69 meter easting correction for TS4

Northing correction at TS4 =

$$\frac{\text{Total northing correction} \times \text{traverse length to TS4}}{\text{total traverse length}}$$

$$= \frac{-6.00 \times 3{,}846.35}{22{,}216.89}$$

$$= \frac{-23{,}078.10}{22{,}216.89}$$

= 1.04 meters northing correction for TS4

9-30. Height Adjustment

Height adjustment is based on the assumption that the error of closure of height is accumulated throughout the traverse in equal amounts at each traverse station and not proportionally to the length of the traverse legs. Errors which may be introduced by such an assumption are negligible for field artillery purposes.

a. Determinining Height Correction. The height correction, which is the error in height with the sign reversed, is determined by comparing the height of the closing point as established by the traverse with the known height of the closing point and applying a sign (±) which will cause the established height, with the correction algebraically applied, to equal the known height.

Example:

Height correction
= known height — height established by traverse
= 478.3 meters — 477.5 meters
= + 0.8 meters

Note. For the height determined by traverse to be equal to the correct height, 0.8 meter would have to be added to the height of the closing station determined by traverse.

b. Application of Height Correction. The height correction is distributed evenly throughout all stations of the traverse with any remainder distributed to those stations computed from the longest legs.

Example: Assume that the traverse, for which the height correction was determined, consists of four stations. To distribute the height correction throughout the traverse, divide the height correction by the total number of stations in the traverse excluding the starting station (a known height). In this case, 0.8 meter ÷ 3 stations = 0.2 meter per station with a remainder of 0.2 meter to be divided and applied equally to those stations computed from the longest legs. The adjustment would be as follows:

Station	*Traverse Height*	*Distance*	*dH*	*Correction*	*Adjusted Height*
Starter	450.4				450.4
		384.5	+21.3	+0.3	
TS1	471.7				472.0
		284.3	+10.7	+0.3	
TS2	482.4				483.0
		269.4	— 4.9	+0.2	
Close	477.5				478.3

Note. The adjustment is an accumulation of the correction since the correction is applied to the differences in height between the stations and not directly to the station heights. The height adjustment can be made on the same form and at the same time that coordinate adjustments are being made.

9-31. Discretion Adjustment

Although traverse adjustment is a systematic operation, there will be times in the field when surveyors may rely on judgment alone. In these cases, the error may be distributed arbitrarily in accordance with the surveyor's estimation of the field conditions. It is reasonable to assume that if certain legs of the traverse are over rough terrain, the error in taping these legs will be relatively large when compared to taping over ideal terrain, and the correction should be correspondingly greater. Or, if lines of sight are steep and visibility is poor, larger angular errors would be expected than if conditions of observing are more nearly ideal; hence, corrections to angles would be larger if the conditions of observing are relatively unfavorable. The artillery surveyor should not resort to this method of adjustment unless he is experienced and has a keen knowledge of where errors are most likely to occur and of their effect on the overall survey. In any event, the field notebook should contain a detailed account of any unfavorable survey conditions, so that it may be used to substantiate any arbitrary adjustments.

Section V. LOCATION OF TRAVERSE ERRORS

9-32. Analysis of Traverse for Errors

A good survey plan when executed by a well-trained party provides for numerous checks in both computations and fieldwork. However, these checks do not always eliminate errors. On the contrary, errors are made both in the fieldwork and in computations and are often not discovered until the survey has been completed. The field artillery surveyor must, therefore, be able to isolate these errors and determine their cause. Often, a critical analysis of both the fieldwork and computations of a survey in error will save additional hours of repetitious labor and computations. At field artillery battalion and battery levels, such short cuts will often pay great dividends in time saved. To rapidly analyze a survey, a well-trained chief of survey party will maintain in the field a sketch, to scale, of each survey as it is being conducted. If a reliable map is available, it will allow him to check on errors which may occur in either the fieldwork or computations. If, upon completion of the survey, an error is apparent, then the following considerations will be made: To isolate an error in a traverse, an assumption must be made that only one error exists. If more than one error exists, isolation of the error will not be possible. Under some conditions when more than one error is present in a traverse, an apparent solution will exist; however, an investigation of the error isolated may show that both fieldwork and computations are correct for the particular station in question. When this condition exists, no effort should be made to continue an analysis; instead, provisions should be made to perform the traverse again in its entirety.

9-33. Isolation of Distance Errors

a. Indications of Distance Errors. A distance error is indicated when—

(1) Azimuth for the traverse closes within tolerance; however,

(2) Coordinate closure is in error beyond the limits allowed for the prescribed accuracy.

b. Isolation of Distance Errors. Compare the known coordinates of the point on which the survey was closed to the computed coordinates determined by survey. From this comparison, determine an error in easting (eE) and an error in northing (eN). Note the sign of each error and compute the azimuth from the known coordinates of the closing station to the computed coordinates of the closing station by using the military slide rule (MSR) or logarithmic tables. The traverse leg in which the distance error is contained will have the same azimuth (or back-azimuth) as that computed (fig 9-21).

In analyzing for an error of this nature, some tolerance and judgment must be used to determine the traverse leg in error. The reason for this is minor errors occur in both angular and distance measurements which are so small as not to effect the overall accuracy, but which are large enough to create some difference in analyzing for errors. Under some circumstances, several legs with azimuths approximating the azimuth of the radial error will approximate the distance error. Check computations for each suspected leg. If there is no error in computations, then each suspected leg must be remeasured until the leg containing the error is found.

9-34. Isolation of Azimuth Errors

a. Indications of Azimuth Error. An azimuth error is indicated when the—

(1) Azimuth does not close within required tolerance.

(2) Coordinate closure is in error beyond the limits allowed for the prescribed accuracy.

b. Isolation of Azimuth Error. Compare the

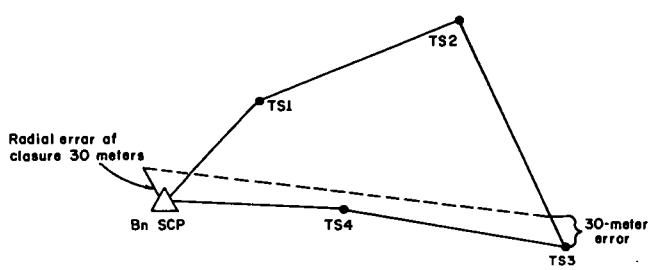


Figure 9-21. Distance error.

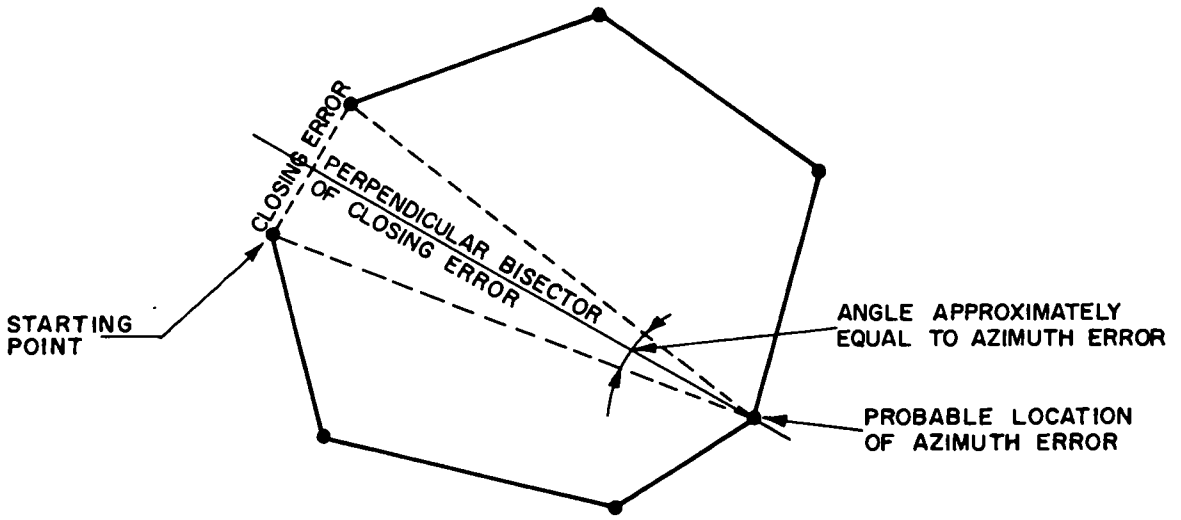


Figure 9–22. Sketch of method of locating azimuth error in traverse.

computed azimuth to the known azimuth to the closing point and determine the azimuth error. Compare the computed coordinates of the closing station to the known coordinates and determine an error in easting (eE) and an error in northing (eN) coordinates. With the MSR or logarithmic tables, compute the length and the azimuth of the radial error. Using a scaled sketch of the traverse, construct a line perpendicular to and at the midpoint of the plotted radial error line. Extend this line in the appropriate direction through the area in which the fieldwork was executed (fig 9–22). The station at which the angular error was made will be on or very near the extended line.

c. Corrective Procedure. After the suspect station is located, a check should be made of computations at that station to include the angular values in the field notes recorded for that station. If no error exists in meaning of angles, then the angle for the station should be remeasured and compared with the recorded angle measured as a part of the original survey. This procedure will expose the error if one exists. If the remeasured angle compares favorably with the recorded angle, then a multiple error exists in the survey and a solution is not possible. When this situation occurs, the survey should be rerun to determine the location of the error.

d. Alternate Solution. Another procedure which may be used to determine the location of the angular error when a graphical plot of the survey is not available is the trial and error procedure conducted as follows: first, to determine suspect stations (stations where the error may exist), compute the distance, using the MSR or logarithms, between the correct coordinates of the closing station and the computed coordinates of the closing station. Second, determine the amount the azimuth is in error on closure by comparing the closing azimuth with the correct grid azimuth at the closing station. Third, using the distance error and the azimuth error, substitute them into the mil relation formula ($\frac{W}{r} = m$) and determine an approximate distance from the closing station to the station in error.

Example:

Radial error of closure = 100 meters
Azimuth error of closure = 10 mils
Use mil relation.

$$\frac{w}{r} = m$$

Substitute,

$$\frac{100}{r} = 10 \text{ mils}$$

Or,

$$r = \frac{100}{10}$$

Or,

r = 10 (10,000 meters = approximate distance of station in error from closing station.)

By using this procedure, one or more suspect stations may be determined and then, by the trial and error procedure and systematic elimination, the suspect station in error will be located as follows: Using the coordinates of the suspect station and the known coordinates of the closing station, compute the azimuth and distance between the two. Using the coordinates of the suspect station and the computed coordinates of the closing sta-

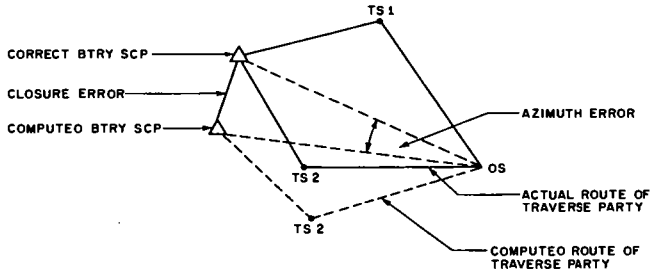


Figure 9-23. Azimuth error.

tion, compute an additional azimuth and distance between these two and compare the results with the azimuth and distance first determined. If the error is at that station, the azimuth should vary by the amount of the azimuth error of closure, and distances should agree relatively closely. If the error is not at the suspect station, the azimuth will disagree but not by an amount equivalent to the azimuth closure error (fig 9-23).

9-35. Isolation of Multiple Errors

Multiple errors are errors in both azimuth and distance or more than one error in either azimuth or distance. When multiple errors are present in a traverse, the indications will be the same as for an azimuth error. It is possible that in following the procedure for azimuth error determination definite suspect stations will be located; however, an analysis of the field work and computations at these stations will not produce the error. When this occurs, the entire traverse should be performed again to locate the errors which were made.

Section VI. TRIG-TRAVERSE

9-36. General

The occasion may arise when conducting a traverse in the field that, due to terrain, it may be impossible to tape or electronically measure a traverse leg. When this occurs a method known as Trig-Traverse may be employed. When properly executed, this method is adequate for accomplishing fourth-order traverse requirements. Trig-Traverse employs the triangular figure, the base of which is carefully measured, the subtended angle measured and the required side (traverse leg) is computed.

9-37. Method

In the Trig-Traverse method, the base of the triangle need not be established perpendicular to the required side of the triangle, but may be established perpendicular to the required side of the triangle, but may be established at an angle more convenient for measurement. Where possible, however, it should be placed perpendicular to the required side using the theodolite to place the base ends at right angles to the desired side. By establishing the base perpendicular, the only angles necessary are the angles subtended by the bases. This also simplifies the computations. If it is not possible to make the base perpendicular, it is necessary to measure the angle formed by the base and the desired side. The base must be long enough to minimize the effects of instrumental error on the distance to be measured. This requires it to be longer than one-twentieth and preferably about one-tenth of the distance to be measured. The error in the computed length caused by .01 mil angular error is shown in figure 9-24. In figure 9-25, the length to be determined is the line AB. To offset the slight inaccuracy that will prevail in the base measurement and to provide a check on the work, two independent bases are measured. The bases are shown by the lines BC_1, and BC_2. The effective base should not be less than 1/20th of the subtended distance.

9-38. Base Accuracy

The accuracy of the base measurement is the key to a successful Trig-Traverse. Where the ratio of the side to be measured to the base length is 20 to 1, an error of 0.01 meter in the determination of the length of the base would result in an error of 0.20 meters in the computed length. Each base should be double taped separately within a comparative accuracy of 1:7,000. The distance C_1 to C_2 is also measured to provide a check. Reasona-

Ratio base to distance	Angle subtended	Error in computed length due to .01th error in angle
1/10	101.531 mils	1/10,200
1/20	50.889 mils	1/5,200
1/25	40.716 mils	1/4,100
1/30	33.951 mils	1/3,400
1/35	29.087 mils	1/2,900
1/40	25.457 mils	1/2,600
1/45	22.642 mils	1/2,300
1/50	20.370 mils	1/2,000

Figure 9-24. Trig-traverse expansion ratio.

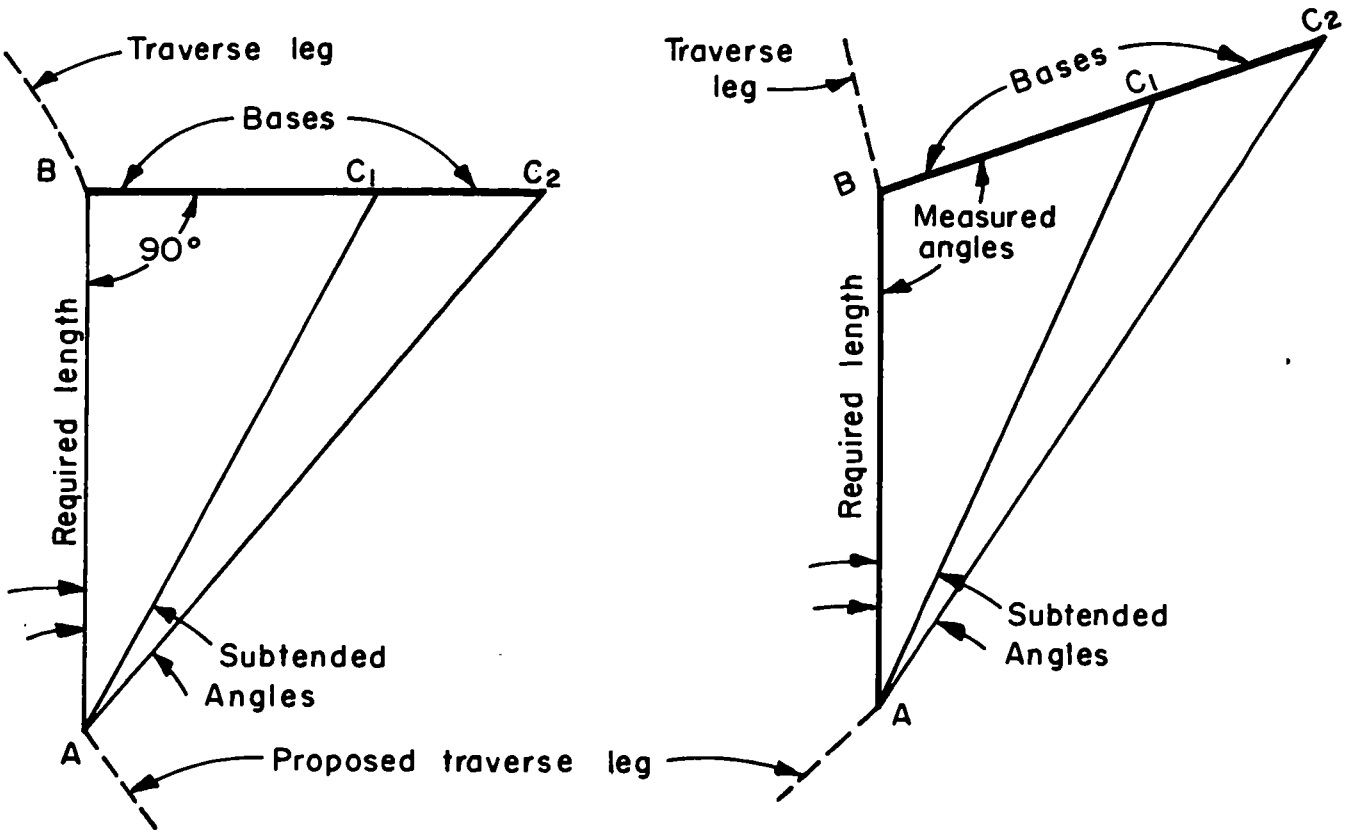


Figure 9-25. Trig-traverse method.

ble control over the accuracy of the distance measurements can be exercised by limiting the ratio of the length of the base to the length to be computed.

9-39. Angles

The .002 mil theodolite is used for angle measurement. Four positions are observed. Any position that varies more than .02 mil from the mean must be rejected and reobserved.

9-40. Targets

Due to the very short range of the pointing to the base end, the targets must be designed for accurate pointings. The string of a suspended plumb-bob may be used to sight on as well as a sharpened pencil point. On longer bases, a range pole may be used, providing the range pole is very carefully plumbed over the point. If available, a tripod-mounted target may also be utilized, and this too, must be carefully leveled and plumbed over the point.

9-41. Length Computation

If the base is perpendicular to the required side, the required side is easily computed by miltiplying the base length by the cotangent of the subtended angle. When the base is not perpendicular to the required side, the distance is computed by the following formula:

$$S = \frac{BC \ \mathrm{Sin}(Q + Y)}{\mathrm{Sin}\ Q}$$

Where S = length of required side, Q = subtended angle, Y = angle formed by the base and the required side, BC = length of base. Two independent lengths are computed, one from each base. The mean of the two computed lengths is the required distance. The reliability of the length determination is indicated by computing a comparative accuracy of the two lengths obtained (fig 9-24).

CHAPTER 10
TRIANGULATION

Section I. GENERAL

10–1. General

a. Triangulation is a method of survey which employs triangular figures to determine survey data. If the values of certain elements of a triangle are known, the values of other elements of the triangle can be computed. *In field artillery surveys, the term "triangulation" is restricted to operations which involve the measurement of all angles within a triangle* (fig 10–1). There are other methods of survey which employ the triangular figure, but the procedures used in the field work and in the computations differ somewhat from the methods used in triangulation. Therefore, these methods of survey are classified in different terms. The three of these methods employed in field artillery survey are as follows:

(1) *Intersection.* Only two of the three interior angles of a triangle are measured. If the length of one side and the size of two angles of a triangle are known, the size of the third angle and the length of the other two sides can be computed (fig 10–2).

(2) *Resection.* The coordinates of an unknown point are obtained by determining the horizontal angles at the unknown point between two or three unoccupied points of known coordinates (fig 10–3).

(3) *Trilateration.* The three sides of a triangle are measured and the three interior angles are computed (fig 10–4).

b. Survey methods employing the triangular figure may be used at all levels of field artillery survey to determine the location of survey control points. It is generally better to use some method of survey which employs these procedures in situations in which the distance or terrain involved make traverse difficult or impossible.

c. Triangulation involves single triangles (fig 10–1) as well as chains or schemes of triangles (fig 10–5). Whether a particular triangle is a single triangle or a part of a scheme of triangles, the

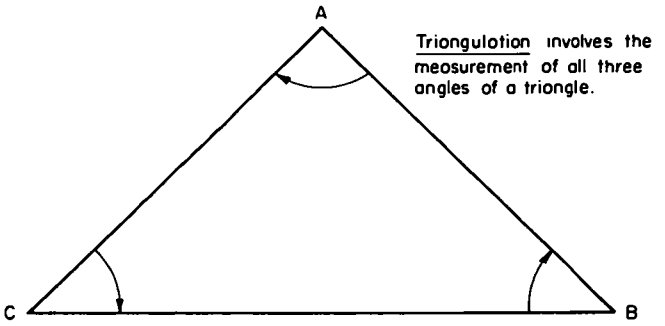


Figure 10–1. Schematic drawing illustrating triangulation.

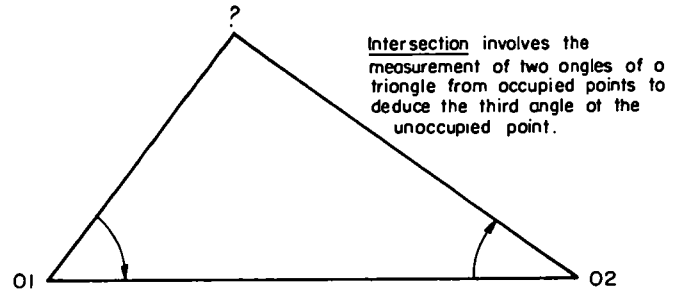


Figure 10–2. Schematic drawing illustrating intersection.

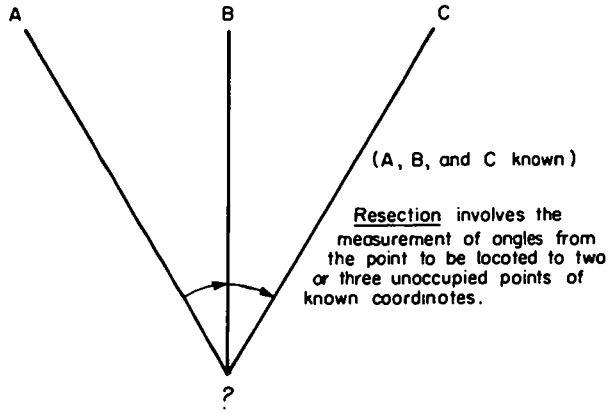


Figure 10–3. Schematic drawing illustrating three-point resection.

angles in the triangle are determined in the same manner, and the unknown elements of the triangle are computed in the same manner. However, in a single triangle, the base (known side) is always determined using electronic distance measuring devices, a 30-meter steel tape, or is computed from known coordinates of the required accuracy; whereas, the length of the base of a triangle in a scheme of triangles may be determined from computation as a side in another triangle.

10–2. Triangulation Parties

a. Triangulation operations are not confined to one area at any one time. There are several operations involved in triangulation. The personnel involved in each phase are usually separated from the personnel performing other phases of the survey. Since different lengths of time are required to perform the various operations, no standard division of duties can be made. There are general operations which must be performed in triangulation and survey personnel are each assigned to one or more of these functions. The general operations are as follows:

(1) Reconnaissance and planning.
(2) Determination of angles.
(3) Base measurement.
(4) Computation.

b. The reconnaissance party normally consists of the survey officer and/or the chief surveyor and such other personnel as deemed necessary. Usually, the reconnaissance party contains 2 or 3 personnel. The reconnaissance party should select and mark each station which will be used in the triangulation scheme. They may also erect a target over each station. If considerable clearing of trees and underbrush is required in the vicinity of the station, this may be accomplished by the reconnaissance party or the angle measuring party. Additional personnel may be required in the party that performs the clearing. (Normally, the time and personnel available to perform artillery surveys preclude extensive clearing of trees and underbrush.)

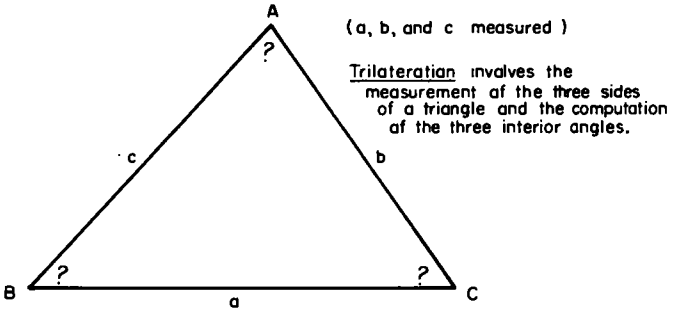


Figure 10–4. Trilateration.

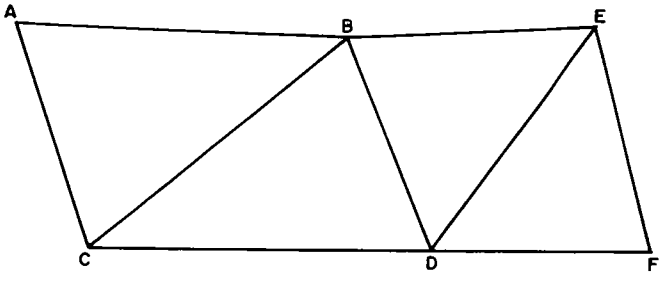


Figure 10–5. Schematic drawing illustrating a single chain of triangles.

c. The angle measurement party normally consists of the instrument operator, the recorder, and (when necessary) personnel for clearing.

d. The base measurement party generally will consist of two taping teams of 2 men each or an electronic measurement team consisting of 2 instrument operators and 2 recorders. (The DME recorders must compute each distance prior to moving instruments.) If taping teams are used, the base will be double taped to a specified comparative accuracy. If only one taping team is available, it must make at least two independent measurements of the base with a specified comparative accuracy. A tension handle with a 25-pound pull must be used and horizontal alinement must be maintained to assure the required accuracy of a taped base measurement. If electronic distance measuring devices are used for the measurement of the base, the base will be measured from both directions to a comparative accuracy of 1:25,000. (Tellurometer MRA–1 measurements will consist of 2 coarse and 4 fine readings.) After completing all required measurements these personnel may be utilized as directed by the chief of party or the survey and reconnaissance officer.

e. The computing party normally consists of two computers. The computers perform independent computations and compare their results. They perform their computations at any convenient location designated by the party chief or the survey officer. Data from the various points in the survey are reported to the computer by some pre-arranged method (i.e., radiotelephone).

10–3. Triangulation Field Notes

a. The base measurements for all bases will be recorded in the taping notebook by the rear tapeman of each of the two taping teams as they are measured. These distances will be transferred to

the field notes in possession of the recorder as soon as practicable. If electronic distance measuring equipment is used, the recorders at both ends of the measured line will compute the distance immediately upon completion of the measurement, and transfer the distance to the field notes as soon as practicable.

b. The field notes kept by the recorder in an angle measurement party are discussed in chapter 8. Figure 8–8, 8–9, and 8–10 are examples of notes kept by a recorder for 1/1000 (0.2 theodolite) and 1/3000 (0.002 mil theodolite) triangulation, respectively. The entries which should be made on the cover, the first half page, and the first page, respectively, of the recorder's notebook for an angle measurement party are shown in figures 8–1 through 8–3.

10–4. Specifications and Techniques

In triangulation, certain specifications and techniques are adhered to in field work and computations to produce surveys of the desired accuracy. These specifications and techniques are as shown in appendix B.

Section II. TRIANGULATION COMPUTATION

10–5. General

A triangleis defined as a closed three sided geometric figure containing three interior angles whose sum equals 3200 mils (180°). Each triangle is solved separately for the lengths of the unknown sides whether it is a single triangle or a triangle in a scheme. The only type of triangulation problem (excluding intersection and resection) involved in artillery surveys is the solution of a triangle in which the values of all 3 angles and the length of 1 side are known. This type of problem is solved for the lengths of the unknown sides, using the law of sines. (a:sinA: :b:sin B: :c:sin C) Figure 10–6 illustrates that this is a straight proportion-type formula which states that the sine of the angle at A is to its opposite side as the sine of the angle at B is to its opposite side or the sine of the angle at C is to its opposite side. If the values of each of the interior angles of the triangle were known and the length of side *a* was known, the law of sines would be transposed as follows:

(1) To determine the length of side b:

$$\text{side } b = \frac{\text{side a} \times \sin \text{angle B}}{\sin \text{angle A}}$$

or so solve using logarithms:

log side b = log side a + log sin angle B − log sin angle A

(To determine the length or side b, antilog the log length of side b).

(2) To determine the length of side c:

$$\text{side } c = \frac{\text{side a} \times \sin \text{angle C}}{\sin \text{angle A}}$$

or to solve using logarithms:

log side c = log side a + log sin angle C — log sin angle A

(To determine the length of side c, antilog the log length of side c).

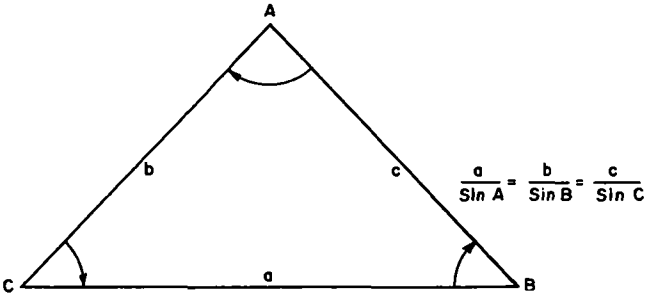


Figure 10–6. Schematic drawing illustrating law of sines as it applies to a basic triangle.

10–6. Survey Application of Basic Triangle

To determine the coordinates (and height) of a point, from a point with known coordinates (and height, three items of information are needed: vertical angle, azimuth and distance. To associate the basic triangle in figure 10–6 with these objectives, assume that point A of this triangle is a point at which the coordinates and height are to be determined by triangulation. In order to accomplish this, the following steps must be taken:

a. Select two other points, B and C, intervisibie to each other and to point A. The coordinates and height of at least one of these two points must be known.

b. Measure the horizontal interior angles and vertical angles at points A, B, and C with an instrument. With one more item, a known side (the base), the triangle can be solved. The specifications for angle measurement for fourth and fifth order accuracies are shown in appendix B.

c. The length of the base can be obtained in one of two ways, either by direct measurement or by

inverse computations. As mentioned previously, the coordinates and height of at least one of points B or C must be known. The specifications for base line measurement for fourth and fifth order accuracies are shown in appendix B.

(1) If the coordinates and height of both B and C are known, the azimuth and length of the base, i.e., the line joining B and C, can be computed on DA Form 6–1. These known coordinates and height must be of an equal or higher accuracy than that of the survey being performed. (If a fourth order survey is being conducted, the coordinates used to compute the azimuth and length of the base *should* be of third order accuracy or better but *must* be at least of fourth order accuracy.).

(2) If the coordinates of only one of the points are known, the base length must be taped or measured by DME and the azimuth must be obtained by astronomical observation, gyroscopic means, or by sighting on a point of known azimuth (Azimuth Mark).

d. Having obtained the three horizontal interior angles, the vertical angles, the azimuth of the base (thus, the azimuths of all three sides), and the length of the base, the triangle can be solved for either the length AB (side c) or AC (side b) using the law of sines. With the length determined for either side *c* or side *b* and the coordinates and height of B or C, the coordinates and height of A can be determined. The decision as to which side to compute will be based on *distance angles.*

Note. The height of A (unknown point) is determined in a manner similar to that in traverse. Reciprocal vertical angles (measuring from both ends of a line) are measured along the forward, or required, side at the "occupied" and "unknown" station, since the length of this is determined in the law of sines computation and must be known to find the dH. Should the instrument operator not know which is the forward side, reciprocal vertical angles will be measured along all three sides of the triangle.

10–7. Distance Angles of a Single Triangle

a. In order for the small errors of measurement to produce the minimum of error in computed values, it is essential that only strong figures be used in triangulation. The most ideal figure is an equilateral triangle. However, field conditions generally render the use of the ideal figures impractical and it is frequently necessary to select figures which only approximate the ideal.

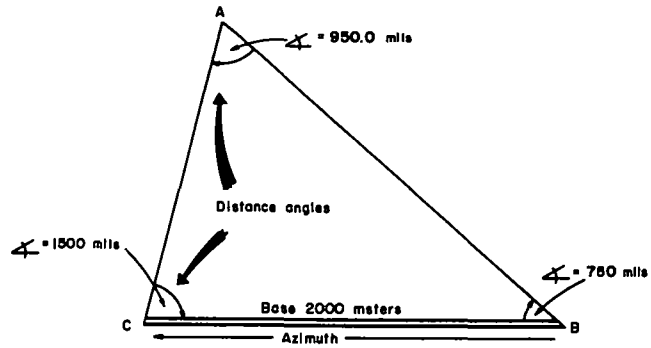


Figure 10–7. Schematic drawing illustrating distance angles of a single triangle.

b. Computation of the length of a side in a triangle involves 2 of the 3 angles in a triangle. The angles which are involved in the computation of the length of a side are called distance angles. Distance angles are defined as those angles in a triangle opposite the known side and the required side (side common to an adjacent triangle). Since in a single triangle there is no specific required side, the distance angles in a single triangle are the angles opposite the known side and the stronger (closest to 90° or 1600 mils) of the two remaining angles (fig 10–7).

c. The difference between the sines of angles near 0 mils and 3200 mils are quite large for very small differences between angles. Because of this, a small error in the value of an angle near 0 mils or 3200 mils will cause a relatively large error in the sine of the angle and a corresponding error in the computed length of the side opposite the angle. For these reasons, distance angles should be between 533 mils (30°) and 2667 mils (150°) for best results. A distance angle must not be less than 400 mils (22½°) or larger than 2800 mils (157½°). It is for this reason that, in the case of a single triangle, the side opposite the stronger angle is the side computed.

Section III. TRIANGULATION SCHEMES

10–8. Description, Solution and Checks of a Single Chain of Triangles

a. A single chain (scheme) of triangles is a series of single triangles connected by common sides (fig 10–5). In a single chain of triangles, only the length of the first or original base and the length of check bases are measured; the lengths of all other sides are computed. In figure 10–8, side AB is common to triangle ABC and ABD. Each of these triangles may be individually solved by

using the Law of Sines, if one side and the interior angles are known. In figure 10-8, assume that it is required to locate an additional point, D, outside the single triangle ABC. While the interior and vertical angles at A and B were being measured, the angles for the new triangle would also be measured. Then the horizontal and vertical angles at point D would be determined. Since side CB is a known side, all the information necessary to compute both triangles would then be available. Side AB would be the required side (side AB is common to both triangles) and angle C would be its distance angle, regardless of its value. As stated in paragraph 10-7*b*, a distance angle is an angle in a triangle opposite the known side and opposite the required side (side common to an adjacent triangle). The required side is also known as the forward line or forward base, because it will become the base for the next triangle in the scheme. In a single chain of triangles, the last triangle in the scheme will be handled as a single triangle, and its distance angles will be determined as discussed in paragraph 10-7*b*. For example, in figure 10-8, the distance angles in triangle ABC are at points A (angle opposite known side CB) and C (angle opposite required side AB), whereas in triangle ABD, the distance angles are at points D (angle opposite known side AB which has been solved in triangle ABD) and point B (the stronger of angles A and B).

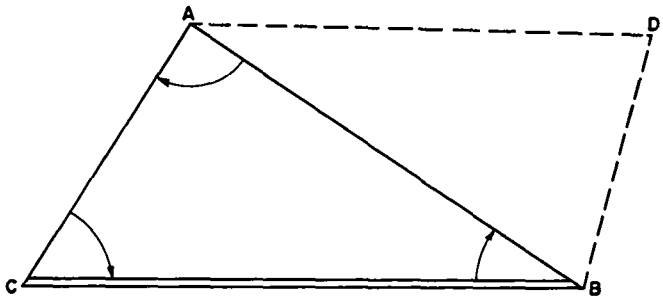


Figure 10-8. Schematic drawing illustrating relationship of a single triangle to a single chain of triangles.

Mils	150	200	250	300	350	400	450	500	550	600	700	800	900	1000	1100	1200	1300	1400	1500	1600
150	605																			
200	465	334																		
250	391	272	212																	
300	347	233	176	143																
350	320	210	155	123	104															
400	300	192	139	109	91	78														
450	283	178	127	97	80	68	58													
500	272	169	119	90	73	61	52	46												
550	264	162	112	84	68	56	47	41	37											
600	257	157	108	80	64	53	44	38	34	31										
700	245	147	99	72	57	46	38	32	28	25	20									
800	236	139	93	67	52	41	33	28	24	21	17	13								
900	229	133	88	62	48	38	30	25	21	19	14	11	9							
1000	223	129	84	59	45	35	27	23	19	17	12	9	7	6						
1100	218	125	81	56	43	33	25	21	17	15	11	8	6	5	4					
1200	215	123	79	55	41	31	24	20	16	14	10	7	5	4	3	2				
1300	211	119	76	52	39	29	22	18	15	13	9	6	4	3	2	2	1			
1400	207	117	74	51	37	28	21	17	14	12	8	5	4	3	2	1	1	0		
1500	205	115	72	49	36	27	20	16	13	11	7	5	3	2	1	1	1	0	0	
1600	202	112	71	48	35	26	19	15	12	10	7	4	3	2	1	1	0	0	0	0
1700	199	110	69	46	34	25	19	14	12	10	6	4	3	2	1	1	0	0	0	
1800	196	108	67	45	33	24	18	14	11	9	6	4	2	2	1	1	0	0		
1900	193	106	66	44	32	23	17	13	11	9	6	4	2	1	1	1	0			
2000	190	104	64	42	30	22	16	13	10	8	5	3	2	2	1	1				
2100	187	102	63	41	30	22	16	12	10	8	5	3	2	2	1					
2200	184	99	61	40	29	21	15	12	9	8	5	3	2	2						
2300	180	97	59	39	28	20	15	11	9	8	5	4	3							
2400	176	95	57	38	27	20	15	11	9	8	6	4								
2500	171	92	55	36	26	20	15	12	10	9	7									
2600	166	89	54	36	26	20	16	13	11	10										
2650	164	88	53	36	26	20	16	14	12											
2700	161	86	53	36	27	21	17	15												
2750	159	85	53	37	28	23	19													
2800	155	84	54	38	31	26														
2850	153	85	56	42	35															
2900	151	87	60	48																
2950	153	94	71																	
3000	163	112																		
3050	202																			

NOTE : The two arguments of the table are the distance angles in mils, the smaller distance angle being given at the top of the table.

Figure 10-9. Table for determining strength figure factors (mils).

b. The size of the distance angles in a triangle is used as the measure of relative strength of the figure. The strength factor of a triangle is determined by use of a Strength of Figure Factor Table (fig 10–9). The distance angles of the triangle serve as arguments for entering the table—the small distance angle dictates the column; the larger distance angle, the row. The smaller the factor, the greater the relative strength of the triangle.

c. When the sum of the strength factors of a chain of single triangles exceeds 200 or at every fifth triangle, a check base (the required side) and azimuth should be determined. If the difference between the computed length and azimuth and the measured length and azimuth is within prescribed tolerances, the scheme may be continued, using the measured data. For fifth-order surveys, the computed length of the check base must agree with the measured length within 1:1,000 (comparative accuracy) and the computed azimuth must agree with the astronomic or gyro azimuth within 0.1 mil times the number of main-scheme stations used to carry the azimuth to the check base. For fourth-order surveys, the check comparisons are 1:3,000 (comparative accuracy) for the base and 0.04 mil × N where N is the number of stations used to carry the azimuth to the check base.

d. A chain of single triangles does not provide sufficient internal checks for an estimation of the accuracy of the work performed. To provide a check, the length of the terminal side of the final triangle is measured and compared with the length computed through the chain of triangles. The results of the base comparison must produce a comparative accuracy as shown in *c* above. If the chain of triangles consists of more than five triangles, the lengths of additonal sides must be measured so that there are no more than five triangles between measured sides. The azimuth of the terminal side should be determined by astronomic or gyroscopic observation at the earliest practicable time. Error in azimuth is determined by comparing the astronomical or gyro azimuth with the azimuth computed through the scheme. If the comparison of the measured values (forward line length and azimuth) with the computed values agrees with the specifications in appendix B, the scheme may be continued using the *measured* data. If the scheme closes on a known point, an accuracy ratio must be determined. The total length used for computing the accuracy ratio is the sum of the length of the sides of the triangles

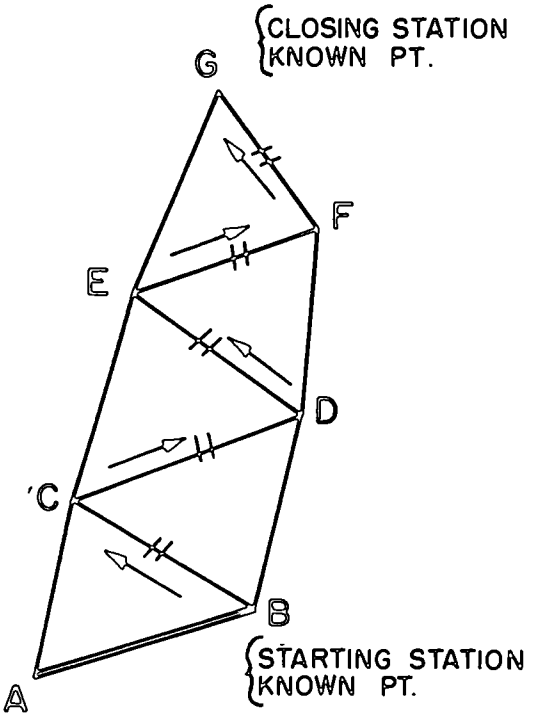


Figure 10–10. Method of determination of distance for accuracy ratio, single chain of triangles.

used to compute coordinates in the scheme from starting station to closing station (fig 10–10). This procedure is usually followed when it is impracticable to measure a check base.

10–9. Triangle Closure

When measuring interior angles of a triangle in the field, the sum of the three angles will vary from 3200 mils by a small amount. The term used in association with this variance is called triangle closure. This is the only adjustment made in field artillery triangulation. If this amount is within tolerance (app B), the angles are adjusted to equal 3200 mils by distributing the closure variance (with sign reversed) equally among the three angle(s), with the odd value being applied to the largest angle. The following example illustrates the procedure for adjusting angles of a triangle:

	Field notes	*Corrections*	*Corrected*
Angle A	= 962.217 mils	—.005 mils	962.212 mils
Angle B	= 1395.689 mils	—.006 mils	1395.683 mils
Angle C	= 842.110 mils	—.005 mils	842.105 mils
Sum	= 3200.016 mils	.016 mils	3200.000 mils

The corrected angles are used to compute the triangle.

10–10. DA Form 6–8

a. A DA Form 6–8 (Computation—Plane Triangle Coordinates and Height from one Side, Three

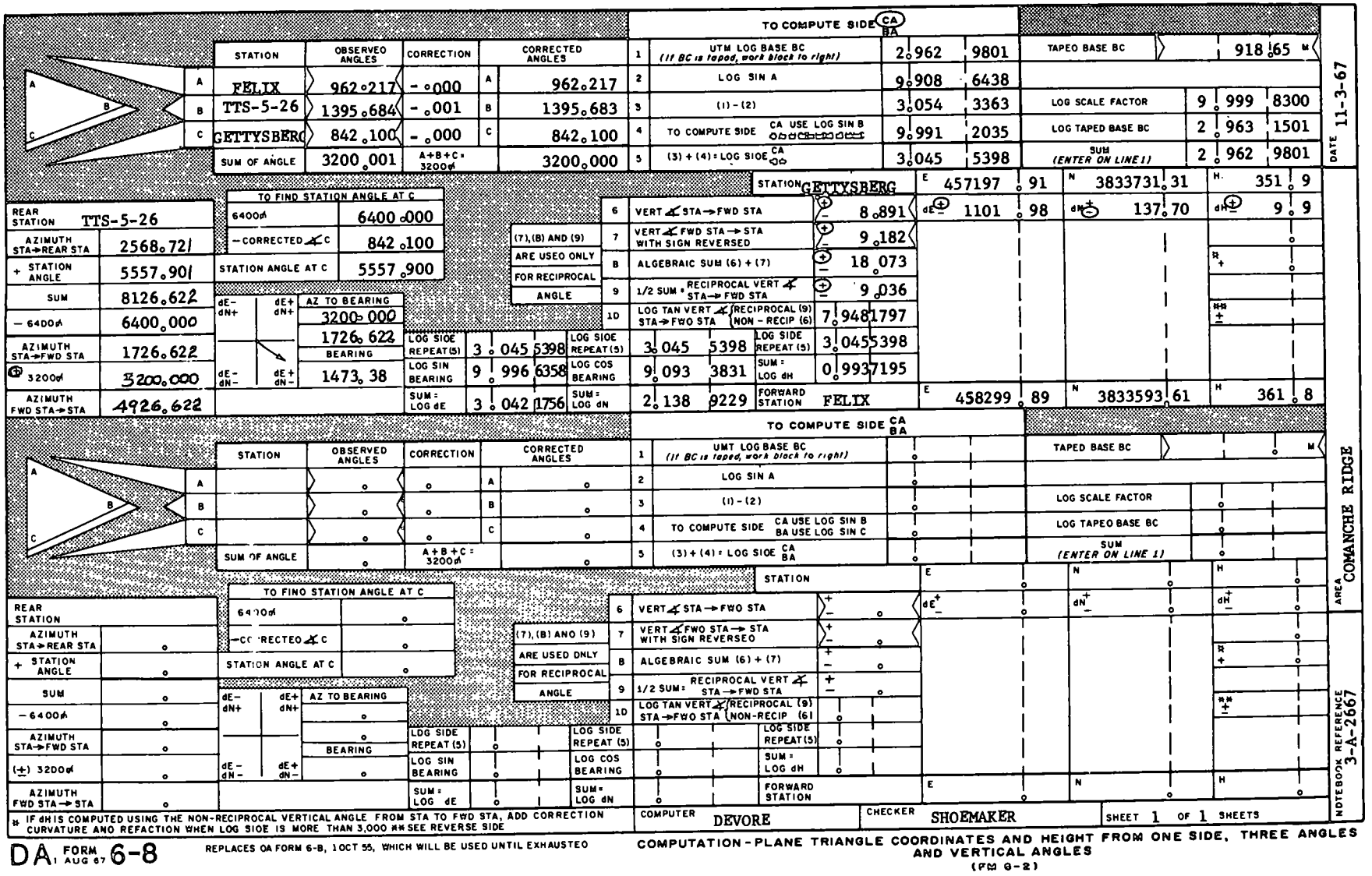


Figure 10–11. Completed DA Form 6–8 showing fourth order triangulation computations.

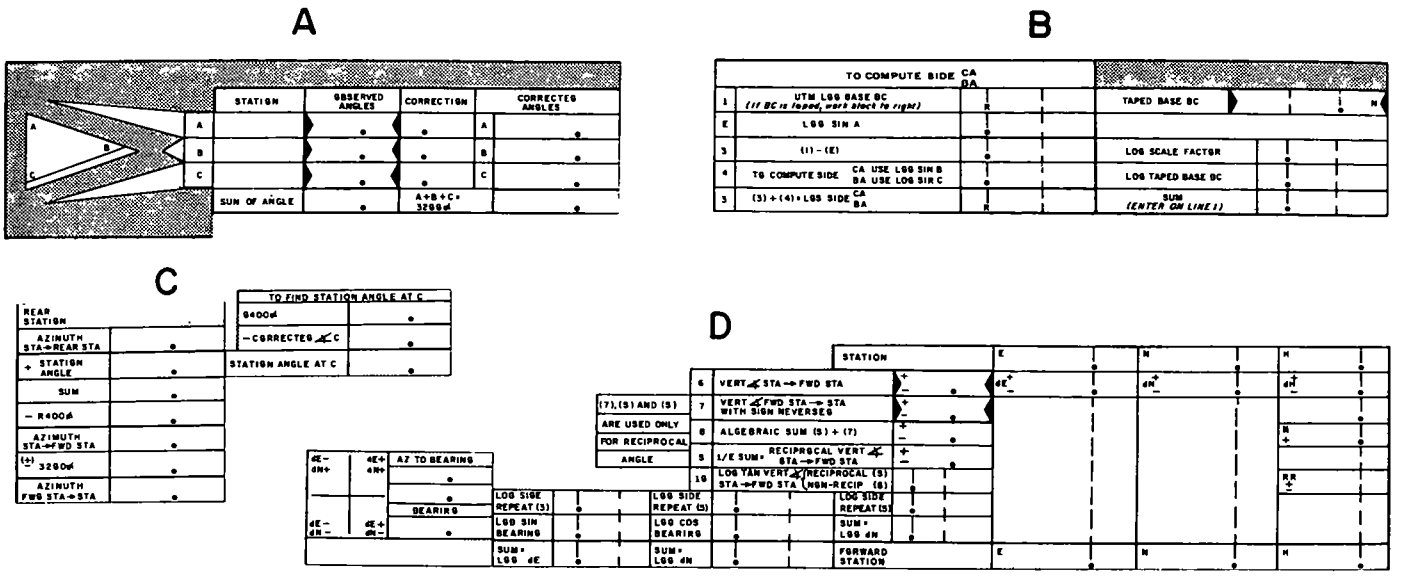


Figure 10–12. Main parts of DA Form 6–8.

Angles and Vertical Angles) is used for the computation of triangulation schemes. In computing single triangles or chains of single triangles, only the front of the form is used. The front of the form is designed for the solution of 2 single triangles. In computing quadrilaterals, both the front and the back of the form are used (para 10–15). It is of the utmost importance to insure that proper orientation is made of the triangle to be computed in the triangular sketch on the front of the form. The known base of the triangle to be computed must always be represented on the sketch as side BC. A sample computation of a single triangle (fourth order) is shown in figure 10–11.

b. Formulas to be used are shown on the back of the form.

c. In figure 10–12, DA Form 6–8 is divided into four major parts labeled A through D. These parts are described in (1) through (4) below in the squence in which they should be computed:

(1) *Part A.* Spaces are provided for entry of the three station names and are keyed to a triangle sketch. As previously stated, the base of the triangle is always the side BC. Angles from the field notebook are recorded in the OBSERVED ANGLES column. The sum of the observed angles is compared to 3,200 mils; if the difference is within the tolerable limits for the order of survey being conducted (app B) the difference is divided by 3 and listed by each station under the CORRECTION column, preceded by the appropriate sign. When the difference is not evenly divisible by 3, the remainder is distributed to the larger angle(s). The results of applying the values in the correction column to the values in the observed angles column are listed in the CORRECTED ANGLES column, together with the total, 3,200 mils.

(2) *Part B.* Two determinations essential to solving the problem are made in part B. In the upper right corner of part B, spaces are provided for determining the logarithm of the UTM grid length of the base by applying the log scale factor. This space is used only when the base (side BC) is taped or is electronically measured. The block to the left is used for the solution of the Law of Sines for either side CA or BA. Instructions printed on the form relating to the side not being solved should be lined out.

(3) *Part C.* This part provides spaces for determining the azimuth B to A or from C to A. The base azimuth must be known and expressed as C to B, if coordinates are to be computed through side CA, or as B to C, if coordinates are to be computed through side BA. The azimuth is added to either the corrected angle at B or the corrected angle at C. If the sum exceeds 6400 mils, then 6400 mils must be subtracted from the total to determine the azimuth. When the corrected angle at C is used, the auxiliary block TO FIND STATION ANGLE AT C is used. The sum is the azimuth from C to A or from B to A and will be used to determine the bearing angle.

(4) *Part D.* This portion of the form is used to reduce the azimuth to a bearing and provides spaces for the computation of dE, dN, and dH and the application of these values to the E, N and H of station B or C. Lines 6 through 10 are used to

COMPUTATION—TRIGONOMETERIC HEIGHTS

OCCUPIED STATION

FORWARD STATION

HORIZONTAL DISTANCE BETWEEN STATIONS — GROUND ☐ UTM GRID ☐

BLOCK I	1	HEIGHT OF INSTRUMENT AT OCCUPIED STATION
	2	HEIGHT OF TARGET AT FORWARD STATION
	3	ALGEBRAIC SUM (1) AND (2)
RECIPROCAL ANGLES ONLY BLOCK II	4	HEIGHT OF INSTRUMENT AT FORWARD STATION
	5	ALGEBRAIC SUM (3) AND (4)
	6	HEIGHT OF TARGET AT OCCUPIED STATION
	7	ALGEBRAIC SUM (5) AND (6)
	8	1/2 OF (7)
	9	VERTICAL ANGLE OCCUPIED STATION TO FORWARD STATION
	10	VERTICAL ANGLE FORWARD STATION TO OCCUPIED STATION WITH SIGN REVERSED
	11	ALGEBRAIC SUM (9) AND (10)
	12	1/2 OF (11)
BLOCK III		NON-RECIPROCAL ANGLES ONLY
	12	VERTICAL ANGLE OCCUPIED STATION TO FORWARD STATION
BLOCK IV	13	LOG OF HORIZONTAL DISTANCE BETWEEN STATIONS
	14	LOG TAN (12)
	15	(13) + (14)
	16	IF HORIZONTAL DISTANCE IS: GRID, USE LOG SCALE FACTOR FROM REVERSE; GROUND, LEAVE BLANK
	17	(15) − (16)
	18	NUMBER HAVING LOG (17) USE SIGN OF (12)
	19	IF BLOCK II IS BLANK REPEAT (3) IF BLOCK II IS FILLED REPEAT (8)
	20	ALGEBRAIC SUM (18) AND (19)
	21	NON-RECIPROCAL ANGLES ONLY: CURVATURE AND REFRACTION CORRECTION FROM REVERSE
	22	ALGEBRAIC SUM (20) AND (21)
	23	HEIGHT OF ☐ OCCUPIED ☐ FORWARD STATION
	24	IF (23) IS HEIGHT OF OCCUPIED STATION REPEAT (22); IF (23) IS HEIGHT OF FORWARD STATION REPEAT (22) WITH OPPOSITE SIGN
	25	ALGEBRAIC SUM (23) AND (24) = HEIGHT OF ☐ OCCUPIED ☐ FORWARD STATION

COMPUTER | CHECKER | SHEET OF SHEETS

NOTEBOOK REFERENCE | AREA | DATE

DA FORM 1 MAY 56 6-2b REPLACES DA FORM 6-2b, 1 OCT 52, WHICH IS OBSOLETE.

Figure 10-13. Front of DA Form 6-2b.

TABLE - CORRECTION FOR CURVATURE AND REFRACTION
(No interpolation necessary for Artillery Survey)
Use only when dH is computed using non-reciprocal vertical angles.
SIGN ALWAYS PLUS
Enter in (21)

Log Dist (M)	Corr (M)
3.079	.1
3.230	.2
3.322	.3
3.386	.4
3.435	.5
3.473	.6
3.508	.7
3.537	.8
3.562	.9
3.584	1.0
3.625	1.2
3.658	1.4
3.687	1.6
3.712	1.8
3.736	2.0
3.784	2.5
3.824	3.0
3.857	3.5
3.886	4.0
3.912	4.5
3.934	5.0
3.955	5.5
3.974	6.0
3.992	6.5
4.007	7.0

TABLE-UTM GRID SCALE FACTORS FOR ARTILLERY

EASTING OF STARTING STATION		LOG SCALE FACTOR
500,000	500,000	9.9998300
490,000	510,000	9.9998300
480,000	520,000	9.9998300
470,000	530,000	9.9998300
460,000	540,000	9.9998300
450,000	550,000	9.9998400
440,000	560,000	9.9998400
430,000	570,000	9.9998500
420,000	580,000	9.9998800
410,000	590,000	9.9998700
400,000	800,000	9.9998800
390,000	610,000	9.9998900
380,000	820,000	9.9999000
370,000	630,000	9.9999200
360,000	640,000	9.9999300
350,000	650,000	9.9999500
340,000	660,000	9.9999700
330,000	870,000	9.9999800
320,000	680,000	0.0000000
310,000	690,000	0.0000200
300,000	700,000	0.0000400
290,000	710,000	0.0000600
280,000	720,000	0.0000900
270,000	730,000	0.0001100
260,000	740,000	0.0001300
250,000	750,000	0.0001600
240,000	760,000	0.0001900
230,000	770,000	0.0002200
220,000	780,000	0.0002500
210,000	790,000	0.0002800
200,000	800,000	0.0003100
190,000	810,000	0.0003400
180,000	820,000	0.0003700
170,000	830,000	0.0004100
160,000	840,000	0.0004500
150,000	850,000	0.0004800
140,000	860,000	0.0005200
130,000	870,000	0.0005600
120,000	880,000	0.0006000
110,000	890,000	0.0006400
100,000	900,000	0.0006900

Given:
UTM grid distance or horizontal ground distance in meters between stations.
Height of one station in meters.

Field data:
Observe vertical angle between instrument at one station and target at other station.
Height of instrument.
Height of target.

Guide:
Enter field data in blocks marked [redacted].
When vertical angles are observed in two directions, either station may be designated as the occupied station. Use Blocks I, II, and IV.
When vertical angle is observed in one direction, use Blocks I, III, and IV. Use curvature and refraction correction from table above.
Elevation of occupied station need not be known.
In (16), obtain approximate easting coordinate of occupied station from other computations or from map. Use this value to obtain scale factor from table above.
If height of either station in (23) is below sea level (-), add 1,000 meters algebraically to (23); proceed with computation as indicated. Subtract 1,000 meters algebraically from (25) to obtain height of station.
If height of occupied station is used in (23), then height of forward station is obtained in (25).
All angular units used in computation must be the same (mils or degrees).

Limitation:
This computation does not provide for reduction of ground distance to sea level distance.

Results:
Height of the unknown station in meters.

Figure 10-14. Back of DA Form 6-2b.

mean vertical angles which were observed in both directions (reciprocal) to height of instrument. When performing fourth-order triangulation, the vertical angles are determined and recorded to the nearest .001 mil and are so entered on lines 6 and 7. The sum of the two vertical angles is determined to the nearest 0.001 mil and entered on line 8. On line 9, when the reciprocal vertical angle is determined, the result is rounded to the nearest 0.01 mil prior to entering the log table. The computations are complete when the coordinates for E, N and H of the forward station have been determined.

d. Vertical angles at each end of the side of a triangle should be measured reciprocally to the height of instrument (HI). Frequently, due to distances involved, the instrument operator must measure the vertical angle to a target erected and plumbed over the forward station. When the vertical angles are measured reciprocally at HI, the heights of triangulation stations are computed on DA Form 6–8. If the length of the side is greater than 1,000 meters and/or if the vertical angle is not measured reciprocally, the table of curvature and refraction corrections on the reverse side of DA Form 6–8 must be used. To enter the table, use the log length of the side along which the height is being extended.

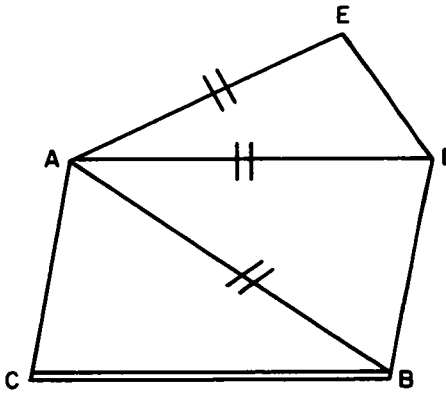


Figure 10–15. Route of trigonometric height computations.

e. When the vertical angle is measured to a target erected over the station or to any point other than height of instrument, the height of the unknown station is computed on DA Form 6–2b (fig 10–13). Complete instructions for the use of DA Form 6–2b are shown on the reverse of the form (fig 10–14). At each stations, the height of instrument and the height of any points which could conceivably be used as a target by other parties will be recorded. Prior to performing the computations, the parties compare notes and determine the heights of target and heights of instruments to be used.

f. In any triangulation scheme, the coordinates and height of at least one station must be known. This station is used as the starting point to obtain the height of the next station. The height control is extended along the forward line of each triangle in the scheme. In figure 10–15, using the height of point C as a starting point, the height of point B is first determined since the height of point A must be computed along the forward line, BA. Once the height of B is determined, the height of A can be determined. Using the height of A, the height of D is computed and also from A, the height of E is determined. Had side DE been the forward line, then the computation would have been from point D to point E.

Section IV. QUADRILATERALS

10–11. General

A quadrilateral is a four-sided figure, used for the extension of survey control and is considered as a closed triangulation scheme. The primary difference between a quadrilateral scheme and a single chain of triangles scheme is that in a quadrilateral two interior angles are measured at each of the four mutually intervisible corners, resulting in two diagonals as shown in figure 10–16. In effect, the result is two single chains of two triangles each, one superimposed on the other. If separated, they would appear as two single chains of triangles (fig 10–17). Triangles ABC and ACD form one chain, and triangles ABD and BCD form the other. It is apparent that if side DC were of known length and side AB were the desired side (forward line), the length of side AB could be computed through two separate schemes, thus introducing a check feature into the fieldwork and computations. Failure of the two computed lengths to agree within an allowable tolerance indicates either an error in computing and/or an error in the fieldwork. Since this method offers a check on the forward line, it is preferred over the single chain of triangles.

10–12. Determining the Forward Line

When a quadrilateral is computed, it is reduced to single triangles, and each triangle is computed separately. First, the azimuth and length of the

base must be determined; second, coordinates and height of at least one station in the scheme must be known; third, the values of the interior angles and vertical angles at each station must be determined; and fourth, the forward line must be selected in order that its length may be computed. In a single quadrilateral, the forward line is always the side opposite the known side (base). If the scheme contains a chain of quadrilaterals, the forward line is that side which is common to adjacent quadrilaterals.

10–13. Strength of Figures

Assume that the quadrilateral in figure 10–17 is to be computed. The coordinates of points C and D are known, so the azimuth and length of the base can be computed on a DA Form 6–1. Each point is then occupied, and the interior and vertical angles are measured. Since side CD is the known side, the opposite side (AB) will be the forward line. The basic quadrilateral actually is two single chains of triangles (fig 10–17), but one chain gives a stronger solution than the other. It would be possible to compute through both chains and arrive at the coordinates and height of A and B and the distance between them, averaging the results to obtain a final answer. This method, however, would not only be time-consuming but would produce a loss of accuracy. By use of strength of figures, one chain is chosen as the principal route (and is designated as the R–1 chain) through which the coordinates and length of the forward line are computed. The other chain provides another route (R–2 chain) by which only the length of the forward line is determined. If the two log lengths of the forward line agree within five digits in the fifth decimal place (0.0000500) of the mantissa, then the field work and the computations

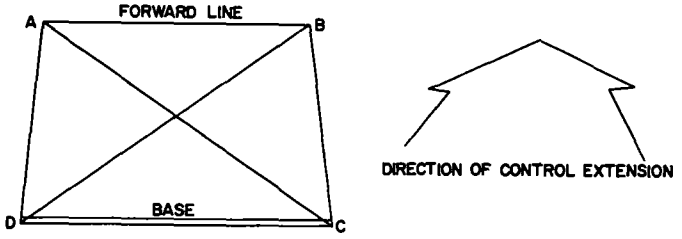


Figure 10–16. A quadrilateral.

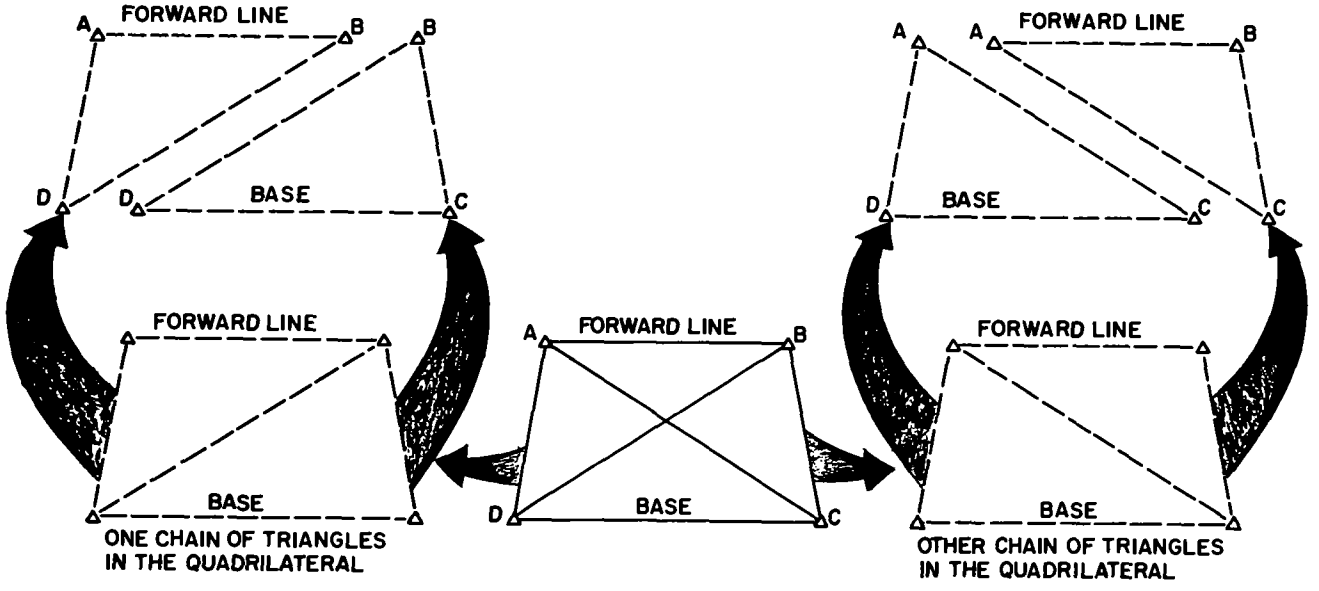


Figure 10–17. A quadrilateral separated into two single chains of two triangles each.

are assumed to be correct and the chain is considered closed. If they do not agree within the tolerance, it indicates either an error in computing or an error in fieldwork and the work must be rechecked.

10–14. Distance Angles

a. The strength of the distance angles in the chain will determine which chain is to be R–1 and which is to be R–2. The chain containing the stronger combination of distance angles will produce the more accurate answer and will be the R–1 chain. The weaker chain will be the R–2 chain. Position coordinates are computed only through both chains. To determine the stronger chain, a table for determining strength of figure factors (fig 10–9) may be used. The two distance angles of each triangle, rounded off to the nearest mil indicated in the figures at the top and on the left side of the table, are used as arguments for entering the table. The small distance angle dictates the column; the larger distance angle, the row. The factors obtained for each triangle of a given chain are then added, and the chain containing the smaller total value is the stronger, or R–1 chain. Figure 10–18 illustrates the determination of the R–1 and R–2 chains. When the distance angles are used to enter the strength of figure table, the relative strength of the chain on the left is found to be 13 and the relative strength of the chain on the right is found to be 17. The chain on the left is the stronger of the two chains and is designated as the R–1 chain. In cases where the strength of figures for the two chains of a quadrilateral are equal, either chain may be designated R–1.

10–15. Computation of Quadrilaterals

DA Form 6–8 is used to compute quadrilatorals (fig 10–19). One form is used to compute each quadrilateral. The R–1 chain is computed on the face of the form and the R–2 chain is computed on the back. Only the log distance of the forward line is sought from the R–2 chain. Spaces are provided on the back of the form for comparing

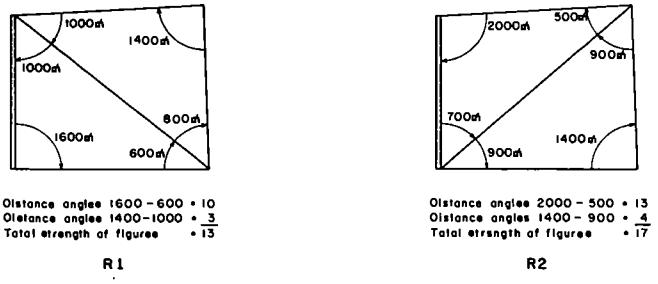


Figure 10–18. Schematic drawing illustrating the determination of R–1 and R–2 chains.

the log distances of the forward line, as computed through both the R–1 and R–2 chains (fig 10–20). If the log lengths agree within 5 in the fifth place of the mantissa, the fieldwork and computations are considered to be correct. The only adjustment necessary for quadrilateral triangles in artillery survey is the adjustment of each triangle for triangle closure. Computation may then be continued, using the R–1 chain only, to solve for the desired coordinates. This procedure will save time, in that if the log lengths do not agree, the previous work must be rechecked and the coordinate solution would not have to be recomputed. This would occur if the entire front of the form had been completed before proceeding to the back of the form.

a. Coordinate Computations. In a single chain of triangles, the forward line in the last triangle of the chain is always opposite the stronger angle and is the side used to compute the coordinates of the forward station. In the R–1 chain of a quadrilateral, however, the coordinates of the forward station are obtained using the forward line, even though this may involve using the weaker angle. Because of the check obtained, through the comparison of the R–1 and R–2 chains, the accuracy of the coordinates obtained is assured. Since the primary reason for using quadrilaterals is to check the computations and fieldwork, the forward line is used to obtain the coordinates of the forward station because its length has been checked.

b. Height Computations. Height computations in quadrilateral schemes usually involve distances in excess of 1,000 meters; therefore, instrument and target heights must generally be obtained at all applicable points and the height computations performed on DA Form 6–2b.

c. Sequence in Quadrilateral Computations. The proper steps to take in computing a quadrilateral are as follows:

(1) Isolate the quadrilateral from the quadrilateral scheme.

(2) Determine the R–1 and R–2 chains.

(3) Compute the R–1 chain on the face of DA Form 6–8.

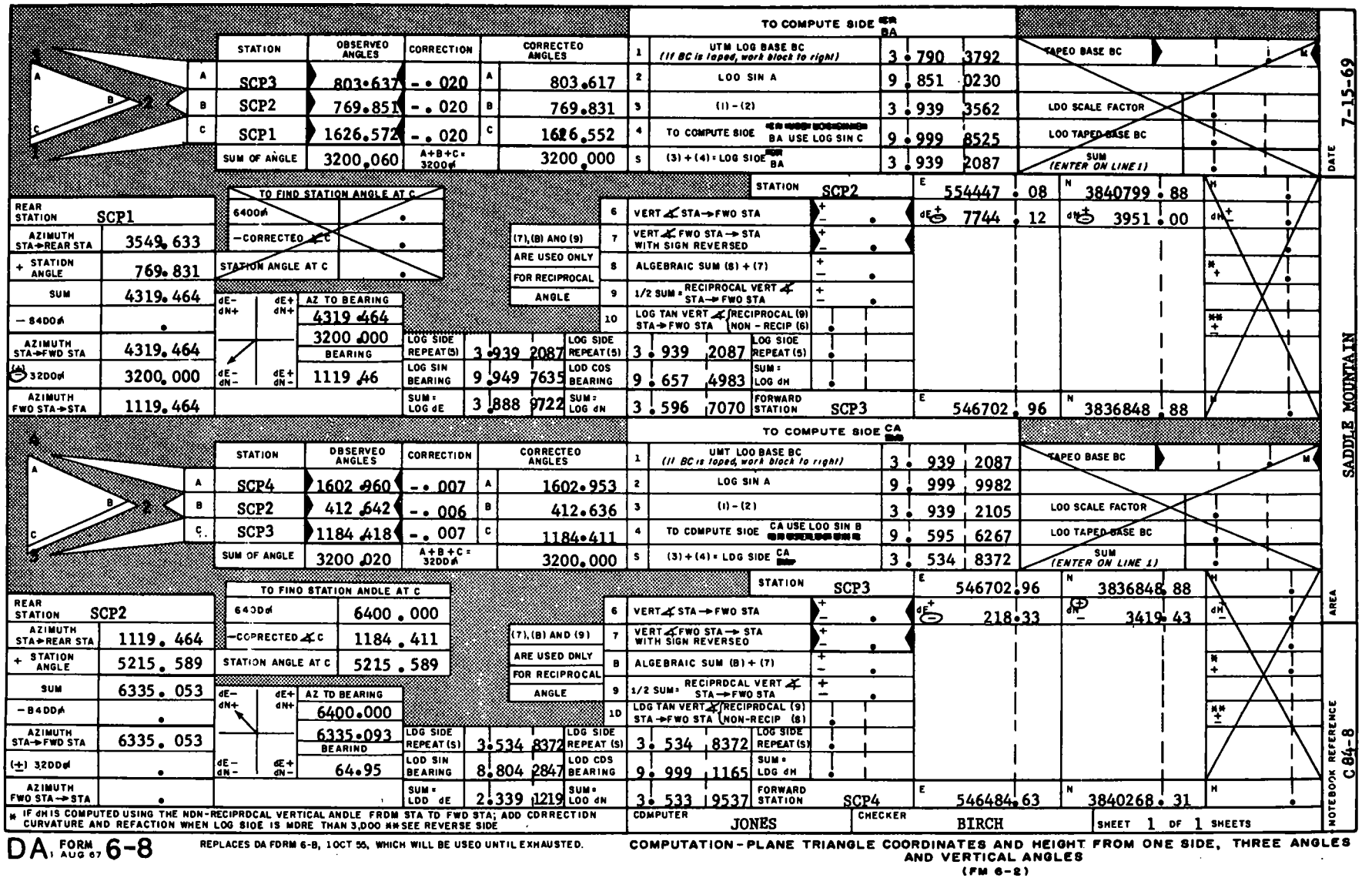
(4) Compute the R–2 chain on the back of DA Form 6–8.

(5) Compare the log distance of the forward line.

(6) Determine coordinates, using the R–1 chain.

(7) Determine heights, using DA Form 6–2b.

d. Right Angle Change of Direction. When a right angle change of direction occurs in a quadri-



STATION	OBSERVED ANGLES	CORRECTION	CORRECTED ANGLES
A SCP3	803.637	-.020	803.617
B SCP2	769.851	-.020	769.831
C SCP1	1626.572	-.020	1626.552
SUM OF ANGLE	3200.060	A+B+C = 3200	3200.000

TO COMPUTE SIDE BA

1	UTM LOG BASE BC (If BC is taped, work block to right)	3.790 3792
2	LOG SIN A	9.851 0230
3	(1) - (2)	3.939 3562
4	TO COMPUTE SIDE BA USE LOG SIN C	9.999 8525
5	(3) + (4) = LOG SIDE BA	3.939 2087

TAPED BASE BC

LOG SCALE FACTOR

LOG TAPED BASE BC

SUM (ENTER ON LINE 1)

DATE 7-15-69

REAR STATION SCP1

AZIMUTH STA→REAR STA	3549.633
+ STATION ANGLE	769.831
SUM	4319.464
- 6400d	
AZIMUTH STA→FWD STA	4319.464
(+) 3200d	3200.000
AZIMUTH FWD STA→STA	1119.464

TO FIND STATION ANGLE AT C

6400d	.
-CORRECTED ∠C	.
STATION ANGLE AT C	.

(7),(8) AND (9) ARE USED ONLY FOR RECIPROCAL ANGLE	

6	VERT ∠ STA→FWD STA	+ - .
7	VERT ∠ FWD STA→STA WITH SIGN REVERSED	+ - .
8	ALGEBRAIC SUM (8) + (7)	+ - .
9	1/2 SUM = RECIPROCAL VERT ∠ STA→FWD STA	+ - .
10	LOG TAN VERT ∠ STA→FWD STA (RECIPROCAL (9) / NON-RECIP (6))	.

AZ TO BEARING: 4319.464 − 3200.000 = 1119.464

LOG SIDE REPEAT (5)	3.939 2087	LOG SIDE REPEAT (5)	3.939 2087
LOG SIN BEARING	9.949 7635	LOD COS BEARING	9.657 4983
SUM = LOG dE	3.888 9722	SUM = LOG dN	3.596 7070

LOG SIDE REPEAT (5) / SUM = LOG dN

STATION SCP2 E 554447.08 N 3840799.88

dE (+) 7744.12 dN (+) 3951.00

FORWARD STATION SCP3 E 546702.96 N 3836848.88

SADDLE MOUNTAIN AREA

STATION	OBSERVED ANGLES	CORRECTION	CORRECTED ANGLES
A SCP4	1602.960	-.007	1602.953
B SCP2	412.642	-.006	412.636
C SCP3	1184.418	-.007	1184.411
SUM OF ANGLE	3200.020	A+B+C = 3200	3200.000

TO COMPUTE SIDE CA

1	UTM LOG BASE BC (If BC is taped, work block to right)	3.939 2087
2	LOG SIN A	9.999 9982
3	(1) - (2)	3.939 2105
4	TO COMPUTE SIDE CA USE LOG SIN B	9.595 6267
5	(3) + (4) = LOG SIDE CA	3.534 8372

TAPED BASE BC

LOG SCALE FACTOR

LOG TAPED BASE BC

SUM (ENTER ON LINE 1)

REAR STATION SCP2

AZIMUTH STA→REAR STA	1119.464
+ STATION ANGLE	5215.589
SUM	6335.053
- 6400d	
AZIMUTH STA→FWD STA	6335.053
(+) 3200d	
AZIMUTH FWD STA→STA	

TO FIND STATION ANGLE AT C

6400d	6400.000
-CORRECTED ∠C	1184.411
STATION ANGLE AT C	5215.589

(7),(8) AND (9) ARE USED ONLY FOR RECIPROCAL ANGLE	

6	VERT ∠ STA→FWD STA	+ - .
7	VERT ∠ FWD STA→STA WITH SIGN REVERSED	+ - .
8	ALGEBRAIC SUM (8) + (7)	+ - .
9	1/2 SUM = RECIPROCAL VERT ∠ STA→FWD STA	+ - .
10	LOG TAN VERT ∠ STA→FWD STA (RECIPROCAL (9) / NON-RECIP (8))	.

AZ TO BEARING: 6400.000 − 6335.093 = 64.95

LOG SIDE REPEAT (5)	3.534 8372	LOG SIDE REPEAT (5)	3.534 8372
LOD SIN BEARING	8.804 2847	LOD COS BEARING	9.999 1165
SUM = LOD dE	2.339 1219	SUM = LOG dN	3.533 9537

LOG SIDE REPEAT (5) / SUM = LDG dH

STATION SCP3 E 546702.96 N 3836848.88

dE (+) 218.33 dN (-) 3419.43

FORWARD STATION SCP4 E 546484.63 N 3840268.31

NOTEBOOK REFERENCE C 84-8

* IF dH IS COMPUTED USING THE NON-RECIPROCAL VERTICAL ANGLE FROM STA TO FWD STA; ADD CORRECTION CURVATURE AND REFACTION WHEN LOG SIDE IS MORE THAN 3,000 ## SEE REVERSE SIDE

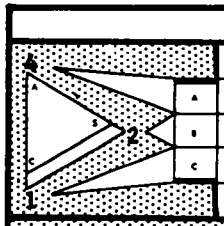
COMPUTER JONES CHECKER BIRCH SHEET 1 OF 1 SHEETS

DA FORM 1 AUG 67 6-8 REPLACES DA FORM 6-8, 1 OCT 55, WHICH WILL BE USED UNTIL EXHAUSTED.

COMPUTATION - PLANE TRIANGLE COORDINATES AND HEIGHT FROM ONE SIDE, THREE ANGLES AND VERTICAL ANGLES (FM 6-2)

Figure 10–19. Front of DA Form 6–8.

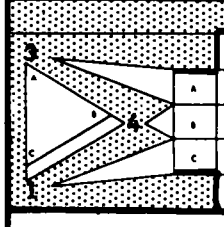
AUXILIARY COMPUTATION



	STATION	OBSERVED ANGLES	CORRECTION		CORRECTED ANGLES
A	SCP4	812 . 701	-.016	A	812 .685
B	SCP2	1182 . 491	-.017	B	1182 .474
C	SCP1	1204 . 858	-.017	C	1204 .841
	SUM OF ANGLES	3200 . 050	A+B+C = 3200 ⍙		3200 .000

TO COMPUTE SIDE CA

1	UTM LOG BASE BC	3	790	3792
2	LOG SIN A	9	854	8246
3	(1) + (2)	3	935	5546
4	TO COMPUTE SIDE CA USE LOG SIN B	9	962	4437
5	(3) + (4) = LOG SIDE CA	3	897	9983



	STATION	OBSERVED ANGLES	CORRECTION		CORRECTED ANGLES
A	SCP3	1988 052	-.017	A	1988 .035
B	SCP4	790 281	-.017	B	790 .264
C	SCP1	421 717	-.016	C	421 .701
	SUM OF ANGLES	3200 050	A+B+C = 3200 ⍙		3200 .000

TO COMPUTE SIDE BA

1	UTM LOG BASE BC	3	897	9983
2	LOG SIN A	9	967	6926
3	(1) + (2)	3	930	3057
4	TO COMPUTE SIDE BA USE LOG SIN C	9	604	5256
5	(3) + (4) = LOG SIDE BA	3	534	8313

STATION		
VERT ∠ STA → FWD STA		
VERT ∠ FWD STA → STA WITH SIGN REVERSED		
ALGEBRAIC SUM		
1/2 SUM = RECIPROCAL VERT ∠ STA → FWD STA		
LOG TAN VERT ∠ STA → FWD STA (RECIPROCAL / NON-RECIP)		
LOG SIDE REPEAT (3)		
SUM = LOG HI		
FORWARD STATION		

COMPARISON OF SIDE LENGTHS

ROUTE 1	3	534	8372
ROUTE 2	3	534	8313
DIFFERENCE	0	000	0059

TABLE - CORRECTION FOR CURVATURE AND REFRACTION

(No interpolation necessary for Artillery Survey) Use only when dH is computed using non-Reciprocal vertical angles (Sign always plus).

LOG SIDE (M)	CORR (M)	LOG SIDE (M)	CORR (M)
3.079	.1	3.712	1.8
3.230	.2	3.736	2.0
3.322	.3	3.784	2.5
3.386	.4	3.824	3.0
3.435	.5	3.857	3.5
3.473	.6	3.886	4.0
3.508	.7	3.912	4.5
3.537	.8	3.934	5.0
3.562	.9	3.955	5.5
3.584	1.0	3.974	6.0
3.625	1.2	3.992	6.5
3.658	1.4	4.007	7.0
3.687	1.6		

** CORRECTION TO d.H. WHEN VERTICAL ANGLE MEASURED TO OTHER THAN H.I.

		OCCUPIED	FORWARD	OCCUPIED	FORWARD
	STATION				
a	HI	•	•	•	•
b	HT	•	•	•	•
c	a + b	+ •	− •	+ •	− •
d	Repeat C	(OCCUPIED)	+ •		+ •
e	Algebraic Sum c + d		+ − •		+ − •
f	1/2e = Correction to d H. enter on front of form **		+ − •		+ − •

GIVEN:
Coordinates and Height of STATION.
Azimuth STATION to REAR STATION.

FIELD DATA:
Observe horizontol angles A, B, and C.
Observe vertical angles to all stations of triangle.
Measure height of torget (to the nearest 0.1 meter) if vertical angles are measured at a point other than HL.
Tape base (BC) unless known from other computations.

GUIDE:
Enter field data in blocks marked. ▭
BC is always the known base.
REAR STATION is station in triangle to which azimuth is known.
STATION is the station for which survey control is known.
FORWARD STATION is the station for which survey control is desired.
RECIPROCAL ANGLE is the mean of the vertical angles observed from each end of a side.
NON-RECIPROCAL ANGLE is a vertical angle which has been measured from station to forward station only.
Best results are obtained when RECIPROCAL ANGLES are used to compute height.

Divide the difference between SUM OF ANGLES and (3200⍙) into three parts and apply as CORRECTION to the OBSERVED ANGLES to obtain CORRECTED ANGLES.
Compute the side (CA or BA) which forms the base of the next triangle.

LIMITATIONS
DISTANCE ANGLES (angles opposite the known base and the computed side) should be greater than (400⍙) or accuracy may fall below standard.
When reciprocal angles are measured to a height of target other than HI use blocks at left marked ** to compute height correction. When non-reciprocal angles are measured to a height of target other than HI, correction = HI at occupied station - HT at forward station when occupied station is the station of known height; or, correction = -HI at occupied + HT at forward when occupied station is of unknown height.

RESULTS:
Coordinates and height of FORWARD STATION.
Azimuth from FORWARD STATION (A) to STATION (B or C).

FORMULAS:
Side CA = $\frac{\text{base BC}}{\text{Sin A}}$ X Sin B;. Side BA = $\frac{\text{base BC}}{\text{Sin A}}$ X Sin C

Figure 10–20. Back of DA Form 6–8.

lateral scheme, a change in the method of computing the forward line is necessary. When this happens, in one of the two pairs of triangles, only one triangle need by considered in the strength determination and the forward base check. For figure 10–21, the forward line of quadrilateral ABCD is

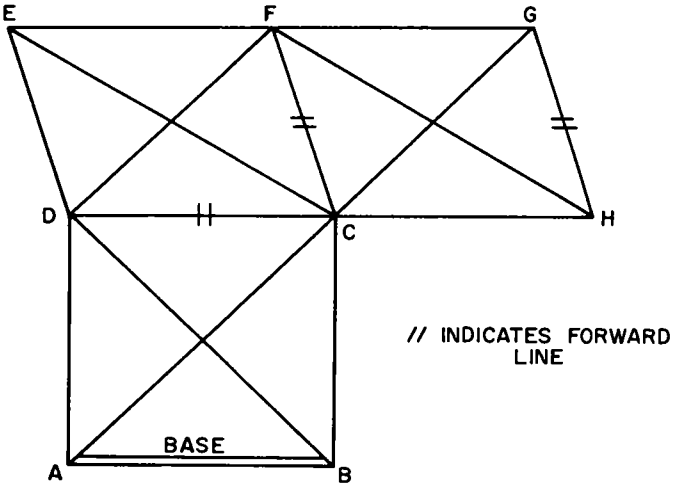


Figure 10–21. Schematic drawing of quadrilateral chain illustrating forward line as side common to adjacent quadrilateral.

CD and is computed in the normal manner. However, in quadrilateral CDEF, the forward side is CF, and a change in the method of computation is necessary. In triangles EDC–ECF, both triangles are used in determining strengths. In triangles DCF–DFE, only triangle DCF is used to compute the strength of this route. If the R–1 chain turns out to be triangle DCF, this triangle will be the only one used in the computations. In effect, triangle DEF is completely omitted from the computations.

e. A survey operation in which quadrilaterals are used should be tied to existing survey control when possible. A completed quadrilateral is considered to be a closed survey; however, a check base should be included to obtain a measure of the accuracy of the scheme. Check bases should be included at every fifth quadrilateral or when the sum of the R–1 strength factors in the chain exceeds 200.

f. To compute an accuracy ratio for a quadrilateral scheme, specifications to be used are the same as in a single chain of triangles using the R–1 chain only.

Section V. CENTRAL POINT FIGURES

10–16. General

When it is not possible to observe the diagonals of a quadrilateral, the central point figure is used. Two central point figures commonly used are shown in figures 10–22 and 10–23. Central point figures with more than five sides are not generally used because of the excessive time and the number of personnel required to accomplish the fieldwork.

10–17. Computation of Central Point Figures

The solution of the central point scheme is similar

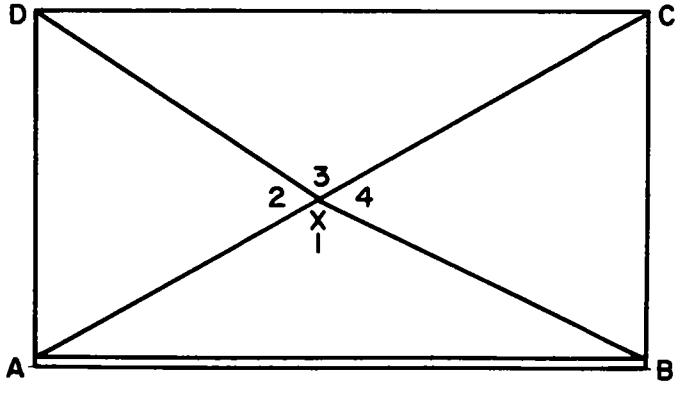


Figure 10–22. Central point quadrilateral.

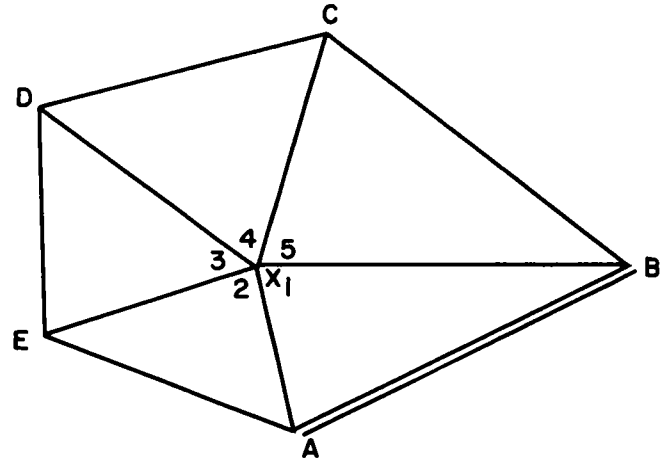


Figure 10–23. Central point pentagon.

to the solution of the basic quadrilateral. The R–1 and the R–2 chains must be determined. In figures 10–22 and 10–23 each scheme contains two chains of triangles, one going clockwise around the central point and the other going counterclockwise. In figure 10–23, if AB were the base and DC the forward line, the chain of triangles going clockwise would contain four triangles and the other chain of triangles going counterclockwise would

contain only three triangles. However, the relative strength of the chain of four triangles may make it the R–1 chain when it is compared to the relative strength of the chain of only three triangles.

Section VI. INTERSECTION

10–18. General

Intersection is a method of survey in which only two angles in a triangle are measured. This type of survey is used primarily in target area survey where target locations cannot be occupied. When using intersection, two interior angles of a triangle are measured. The third angle is determined by subtracting the sum of the two measured angles from 3,200 mils (180°). Intersection can also be used as a means of checking the coordinates and height of surveyed points established by other survey methods. A point located by the intersection method should be observed from at least three known stations (two adjoining bases) of an equal or higher order of survey than the survey being conducted. The computed length of the common side of the resultant triangles must agree within the prescribed accuracy limits for the specific project to be considered as a closed survey (i.e., a 1:1,000 required accuracy must produce a 1:1,000 comparative accuracy on the common side). Intersection field notes are maintained in the field notebook in the same manner as the recording for triangulation.

10–19. Limitations

As in triangulation, no distance angle in the triangle should be less than 400 mils (22½°) or greater than 2,800 (157½°), and an angle between 533 mils (30°) and 2,667 mils (150°) is preferred. The only exception to this is when intersection is used in target area survey when the apex (forced) angle should not be less than 150 mils (8° 26′ 20″) and should preferably be at least 300 mils (16° 52′ 40″).

10–20. Intersection Computations

Intersection computations are the same as those used for triangulation except that, on the DA Form 6–8, the unmeasured angle must be computed and the angles in the triangle do not require adjustment.

Section VII. RESECTION

10–21. Three-Point Resection

a. Three-point resection is a method of survey which is used to obtain control for an unknown point based on three inaccessible known points. However, before the fieldwork is begun, several factors must be considered. In figure 10–24, points A, B, and C are the known points and point P is the occupied station for which coordinates are to be determined. All points must be selected so that angles P_1, P_2, C and B are at least 400 mils (22½°) and preferably more than 533 mils (30°). In addition, if the sum of the angles P_1, P_2, and A_1 is between 2,845 mils (160°) and 3,555 mils (200°), no valid solution is possible. This simply means that station P lies on or near a circle passing through stations A, B, and C. To eliminate the possibility of this occurring, a map reconnaissance must be made. The fieldwork consists of measuring horizontal angles P_1 and P_2 and the vertical angle to either station A, B, or C, preferably point A. The location of station P is determined by using the two measured angles subtended by three visible stations (A, B, and C), and by solving the triangles involved. Resection field notes are recorded in the field notebook in the same basic for-

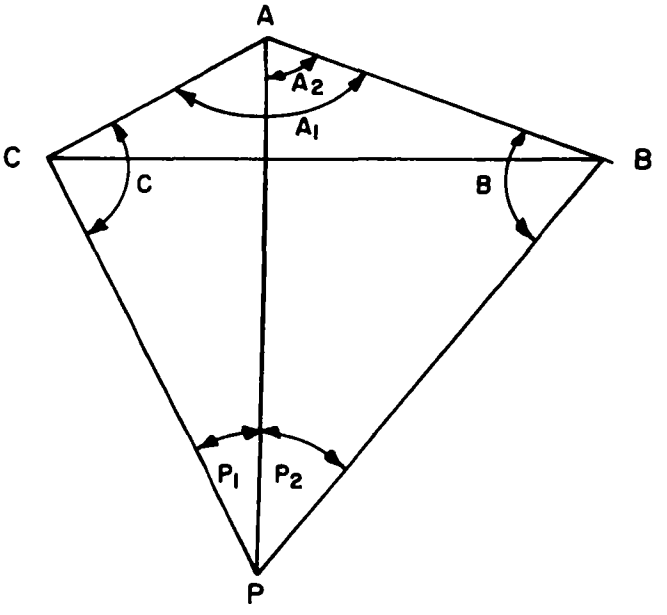
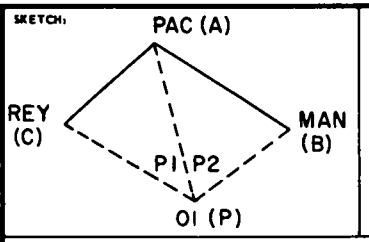


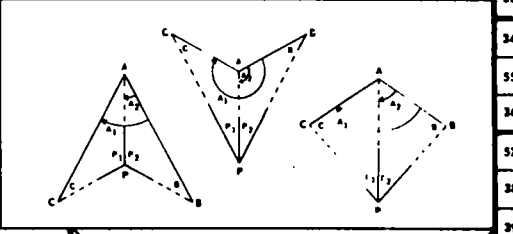
Figure 10–24. Schematic drawing of a three-point resection.

COMPUTATION—COORDINATES AND HEIGHT FROM THREE-POINT RESECTION

1	AZIMUTH A TO C (FROM AUX COMP OR REV)	18 56 020
2	360° OR 6400ᵈ	
3	IF (1) IS: MORE THAN (4) LESS THAN (4) — (3) IS: REPEAT (1) / (1) + (2)	18 56 020
4	AZIMUTH A TO B (FROM AUX COMP OR REV)	14 61 520
5	(3) − (4) = ANGLE A_1	3 94 500
6	OBSERVED ANGLE F_1	8 53 580
7	OBSERVED ANGLE F_2	12 62 864
8	(5) + (6) + (7) DO NOT ATTEMPT TO SOLVE PROBLEM WHEN THIS VALUE IS BETWEEN {160° / 2845ᵈ} AND {200° / 3555ᵈ}	25 10 944
9	180° OR 3200ᵈ	32 00 000
10	1/2 OF (8)	12 55 472
11	(9) − (10)	19 44 528
12	LOG GRID DISTANCE A TO C (FROM AUX COMP OR REV)	3.839 6619
13	LOG SIN (7)	9.975 7636
14	(12) + (13)	3.815 4255
15	LOG GRID DISTANCE A TO B (FROM AUX COMP OR REV)	3.862 7442
16	LOG SIN (4)	9.871 1681
17	(15) + (14)	3.733 9123

SKETCH:





IF (14) IS MORE THAN (17)			IF (14) IS LESS THAN (17)		
18	REPEAT (14)	3 815 4255	18	REPEAT (17)	
19	REPEAT (17)	3 733 9123	19	REPEAT (14)	
20	(18) − (19)	0 081 5132	20	(18) − (19)	
21	ANGLE HAVING LOG TAN (20)	8 95 030	21	ANGLE HAVING LOG TAN (20)	
22	45° OR 800ᵈ	8 00 000	22	45° OR 800ᵈ	
23	(21) − (22)	95 030	23	(21) − (22)	
24	LOG TAN (23)	8.971 1232	24	LOG TAN (23)	
25	LOG TAN (11)	0.453 7540	25	LOG TAN (11)	
26	(24) + (25)	9.424 8772	26	(24) + (25)	
27	REPEAT (11)	19 44 528	27	REPEAT (11)	
28	ANGLE HAVING LOG TAN (26)	2 64 810	28	ANGLE HAVING LOG TAN (26)	
29	IF (27) IS: MORE THAN {90° / 1600ᵈ} LESS THAN {90° / 1600ᵈ} — (29) IS: (27) + (28) / (27) − (28)	22 09 338	29	IF (27) IS: MORE THAN {90° / 1600ᵈ} LESS THAN {90° / 1600ᵈ} — (29) IS: (27) − (28) / (27) + (28)	
30	IF (27) IS: MORE THAN {90° / 1600ᵈ} LESS THAN {90° / 1600ᵈ} — 30 IS: (27) − (28) / (27) + (28)	16 79 718	30	IF (27) IS: MORE THAN {90° / 1600ᵈ} LESS THAN {90° / 1600ᵈ} — 30 IS: (27) + (28) / (27) − (28)	

31	REPEAT (30)	16 79 718
32	REPEAT (7)	12 62 864
33	(31 + 32)	29 42 582
34	180° OR 3200ᵈ	32 00 000
35	REPEAT (33)	29 42 582
36	(34) − (35) = ANGLE A_3	2 57 418
37	REPEAT (15)	3.862 7442
38	LOG SIN (30)	9.998 6685
39	(37) + (28)	3.861 4127
40	REPEAT (13)	9.975 7636
41	(39) − (40)	3.885 6491
43	REPEAT (12)	3.839 6619
45	LOG SIN (29)	9.917 1590
44	(42) + (43)	3.756 8209
45	REPEAT (16)	9.871 1681
46	(44) − (45)	3.885 6528
47	REPEAT (41)	3.885 6491
48	DIFFERENCE BETWEEN (46) AND (47) [MUST BE LESS THAN 0.0001]	0.000 0037
49	1/2 OF (48)	0.000 0018
50	REPEAT (46) OR (47) WHICHEVER IS SMALLER	3.885 6491
51	(49) + (50) = LOG GRID DISTANCE A TO P	3.885 6509

DATE 25 Sept 1963 — AREA FOXTROT — NOTEBOOK REFERENCE 1-10-58

REAR STATION B: MAN

AZ A TO B REPEAT (4)	14 61 520
STA ANGLE REPEAT (36)	2 57 418
SUM	17 18 938
− 360° 6400ᵈ	
AZIMUTH A TO P	17 18 938
(+) (−) 180° 3200ᵈ	32 00 000
AZIMUTH P TO A	49 18 938

dE− dN+ | dE+ dN+ | dE− dN− | dE+ dN−

AZ TO BEARING	
	32 00 000
	17 18 938
BEARING	
	14 81 06

REPEAT (51)	3 885 6509	REPEAT (51)	3 885 6509	REPEAT (51) 3.885 6509
LOG SIN BEARING	9 997 0324	LOG COS BEARING	9 066 3404	SUM = LOG dN 1.681 7959
SUM = LOG dE	3 882 6833	SUM = LOG dN	2 951 9913	

* DIFFERENCE IN HEIGHTS OF TARGET AND INSTRUMENT FROM GUIDE ON REVERSE

** CORRECTION FOR CURVATURE AND REFRACTION FROM TABLE ON REVERSE

STATION A: PAC

VERT ∠ P TO A WITH SIGN REVERSED: (+) 6 37

LOG TAN VERT ∠: 7.796 1450

STATION P	01	
COMPUTER	Cpl Webb	
CHECKER	Cpl Many	

E	546 702 .94	
dE (+) (−)	7 632 .79	
N	3 836 848 .87	
dN (+) (−)	895 .35	
E	554 335 .73	
N	3 835 953 .52	

N	329 .4
dN (+) (−)	48 .1
* (+) (−)	
	377 .5
** −	4 .0
H	373 .5

SHEET 1 OF 1 SHEETS

DA FORM 1 FEB 56 6-19 PREVIOUS EDITIONS OF THIS FORM ARE OBSOLETE.

Figure 10–25. DA Form 6–19, 3-point resection computations.

AUXILIARY COMPUTATION
AZIMUTH AND DISTANCE FROM A TO B AND A TO C

STATION		E COORDINATE		N COORDINATE
FROM STATION A PAC	A	546 702.94	A	3 836 848.87
TO STATION B MAN	B	553 925.95	B	3 837 836.95
IF A IS LESS THAN B REPEAT A	AA	546 702.94	AA	3 836 848.87
IF AA IS BLANK, USE A–B, SIGN– IF AA IS PILLED, USE B–AA, SIGN+	dE	+ 7 223.01	dN	+ 988.08

dE– dN+ | dE+ dN+ | dE– dN– | dE+ dN–

LOG dE	3.858 7182	ANGLE HAVING LOG TAN BEARING A TO B	14 61 520
LOG dN	2.994 7921	DETERMINE AZIMUTH FROM BEARING BY PUTTING dE AND dN ON SKETCH AS GUIDE	
LOG dE – LOG dN = LOG TAN BEARING A TO B	0.863 9261	AZIMUTH A TO B [ENTER IN (4) ON FRONT]	14 61 520

IF dE IS MORE THAN dN		IF dE IS LESS THAN dN	
REPEAT LOG dE	3.858 7182	REPEAT LOG dN	
LOG SIN BEARING A TO B	9.995 9740	LOG COS BEARING A TO B	
LOG dE – LOG SIN BEARING = LOG GRID DISTANCE A TO B	3.862 7442	LOG dN – LOG COS BEARING = LOG GRID DISTANCE A TO B	

[ENTER LOG GRID DISTANCE A TO B IN (15) ON FRONT]

STATION		E COORDINATE		N COORDINATE
FROM STATION A PAC	A	546 702.94	A	3 836 848.87
TO STATION C REY	C	553 398.65	C	3 835 129.58
IF A IS LESS THAN C REPEAT A	AA	546 702.94	AA	
IF AA IS BLANK, USE A – C, SIGN – IF AA IS FILLED, USE C – AA, SIGN+	dE	+ 6 695.71	dN	– 1 719.29

dE– dN+ | dE+ dN+ | dE– dN– | dE+ dN–

LOG dE	3.825 7966	ANGLE HAVING LOG TAN BEARING A TO C	13 43 980
LOG dN	3.235 3492	DETERMINE AZIMUTH FROM BEARING BY PLOTTING dE AND dN ON SKETCH AS GUIDE	32 00.000
LOG dE – LOG dN = LOG TAN BEARING A TO C	0.590 4474	AZIMUTH A TO C [ENTER IN (1) ON FRONT]	13 43.980 / 18 56.020

IF dE IS MORE THAN dN		IF dE IS LESS THAN dN	
REPEAT LOG dE	3.8257966	REPEAT LOG dN	
LOG SIN BEARING A TO C	9.9861347	LOG COS BEARING A TO C	
LOG dE – LOG SIN BEARING = LOG GRID DISTANCE A TO C	3.8396619	LOG dN – LOG COS BEARING = LOG GRID DISTANCE A TO C	

[ENTER LOG GRID DISTANCE A TO C IN (12) ON FRONT]

TABLE - CORRECTION FOR CURVATURE AND REFRACTION

(NO INTERPOLATION NECESSARY FOR ARTILLERY SURVEY)

(SIGN ALWAYS MINUS)

Log Side (M)	Corr (M)	Log Side (M)	Corr (M)
3.079	.1	3.712	1.8
3.230	.2	3.736	2.0
3.322	.3	3.784	2.5
3.388	.4	3.824	3.0
3.435	.5	3.857	3.5
3.473	.6	3.886	4.0
3.508	.7	3.912	4.5
3.537	.8	3.934	5.0
3.562	.9	3.955	5.5
3.584	1.0	3.974	6.0
3.625	1.2	3.992	6.5
3.658	1.4	4.007	7.0
3.687	1.6		

GIVEN:

Coordinates of stations A, B, and C.
Height of station A.

FIELD DATA:

Observe horizontal angles P_1 and P_2.
Observe vertical angle to station A.
Measure height of instrument (to nearest 0.1 meter).
Estimate height of target at station A, if not known.

GUIDE:

Enter observed field data in blocks marked [ ].
When value in (8) of computation is between 160° (2845mils) and 200° (3555mils), a new station P or new stations A, B, and/or C must be selected.
Find difference between heights of instrument and target as follows:

a	Known or Estimated Height of Target	+
b	Measured Height of Instrument	–
c	Algebraic Sum a and b [Enter, with sign, in block marked ✱]	

Enter correction for curvature and refraction in block marked ✱✱

LIMITATIONS:

Angles P_1, P_2, B, and C should be greater than 22 1/2° (400mils) or accuracy may fall below standard.

RESULTS:

Coordinates and height of station P.
Azimuth from station P to station A.

FORMULAS:

$$\text{Tan } \bar{z} = \frac{AC \sin P_2}{AB \sin P_1} \quad \text{or} \quad \text{Tan } \bar{z} = \frac{AB \sin P_1}{AC \sin P_2}$$

If 1/2 (B+C) is more than $\left\{\begin{matrix}90^\circ \\ 1600\text{mils}\end{matrix}\right\}$:

$$\text{Tan } 1/2 (C-B) = \text{Tan } (\bar{z} - 45^\circ) \text{ Tan } 1/2 (B+C)$$

If 1/2 (B+C) is less than $\left\{\begin{matrix}90^\circ \\ 1600\text{mils}\end{matrix}\right\}$:

$$\text{Tan } 1/2 (B-C) = \text{Tan } (\bar{z} - 45^\circ) \text{ Tan } 1/2 (B+C)$$

If 1/2 (B+C) is more than $\left\{\begin{matrix}90^\circ \\ 1600\text{mils}\end{matrix}\right\}$:

$$\text{Tan } 1/2 (B-C) = \text{Tan } (\bar{z} - 45^\circ) \text{ Tan } 1/2 (B+C)$$

If 1/2 (B+C) is less than $\left\{\begin{matrix}90^\circ \\ 1600\text{mils}\end{matrix}\right\}$:

$$\text{Tan } 1/2 (C-B) = \text{Tan } (\bar{z} - 45^\circ) \text{ Tan } 1/2 (B+C)$$

$$AP = \frac{AB \sin B}{\sin P_2} = \frac{AC \sin C}{\sin P_1}$$

$\bar{z}$ = an auxiliary angle required only in the computation (always between 45 and 90 degrees).

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Figure 10–26. Solution to illustrative three-point resection problem.

mat as triangulation except that the height of target (known or estimated) and the height of instrument (measured to the nearest 0.1 meter) are also recorded in the REMARKS section. A three-point resection problem may be considered as a closed survey, providing a fourth known point is used and an accuracy ratio, which meets the specified position closure requirement, is determined (para 10–21*e*(1)).

b. DA Form 6–19 (Computation—Coordinates) (fig 10–25 and 10–26) is used for the computation of a three-point resection problem. The front side of the form (fig 10–25) is divided into two major sections; line 1 through 51 are for determination of log grid distance A to P and angle A_2. The bottom of the form is designed for coordinate and height computations. The back of the form (fig 10–26) is designed as a DA Form 6–1 for computation of azimuth and distance from A to B and A to C. A table for correction of curvature and refraction and a space for determining difference in height of instrument and height of target are also included.

c. Entries required are the coordinates of points A, B, and C (location must be of an equal or higher survey accuracy than that of the survey being performed), the horizontal angles and vertical angles measured at point P and the height of point A.

d. The formulas to be used are shown on the back of the form.

e. When possible, the following checks are performed to verify data obtained by three-point resection.

(1) A horizontal angle to a fourth known station is measured. This will give another three-point resection from which the coordinates of point P_1 (a second location of P) may be determined. An accuracy ratio is computed as follows:

$$AR = \frac{1}{\text{computed distance from pt P to closest known pt (A, B, or C)} \div \text{radial error } (P - P_1)}$$

(2) An astronomic azimuth or gyroscopic azimuth is obtained to check the azimuth.

(3) If a fourth point (1 above) is not known, then point P must be verified by some other method of survey before it can be utilized to extend control.

10–22. Two-Point Resection

a. Two-point resection. This is a method of survey similar to three-point resection. In two-point resection, control is obtained from two known points. In figure 10–27, points A and B are inaccessible points of known survey control. Points R and Q are points from which the other three points are visible. This scheme resembles a quadrilateral, except that the angles at points A and B are not measured. As with three-point resection, certain preliminary operations must be performed. Map reconnaissance is required to insure that all interior angles will be greater than 400 mils (22½°) and less than 2,800 mils (157½°) and preferably between 533 mils (30°) and 2,667 mils (150°). Also, points A and B must be visible from points R and Q as well as points R and Q must be intervisible. Fieldwork will consist of measuring angles R_1, R_2, Q_1, and Q_2 and vertical angles to point A from points R and Q.

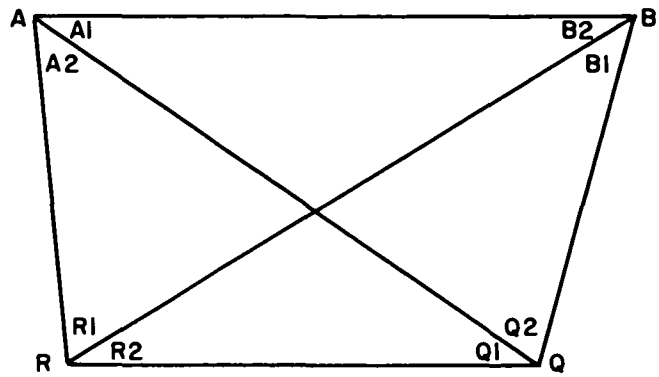


Figure 10–27. Two-point resection.

b. DA Form 6–18.

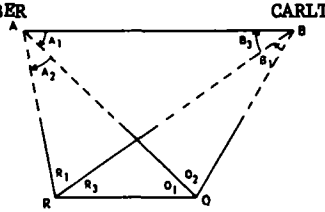
(1) DA Form 6–18 (Computation—Coordinates and Height From Two-point Resection) (fig 10–28 and 10—29) is used for the computations of a two-point resection problem. If only the coordinates of point R are desired, the section labeled TO LOCATE STATION Q, lines 36 to 40, are not used. Similarly, if only the location at point Q is desired the section labeled TO LOCATE STATION R, lines 41 to 45, are not used. The front side of the form (fig 10–28) is divided into two major sections—lines 1 through 45 are for solution of angles A_1 and B_2 and log grid distances A to Q and A to R. The bottom of the form is designed for coordinate and height computations of stations R and Q from station A. The back of the form (fig 10–29) is designed as a DA Form 6–1 for computation of azimuth and distance from A to B. A table for correction of curvature and refraction and a space for determining difference in height of instrument and height of target are also included.

COMPUTATION - COORDINATES AND HEIGHT FROM TWO-POINT RESECTION

(TM 6-200)

1	OBSERVED ANGLE O_1	5 15 507
3	OBSERVED ANGLE R_3	9 33 678
3	(1) + (3)	14 49 185
4	OBSERVED ANGLE R_1	12 05 432
		32 00 000
5	(3) + (4) [ENTER ON THIS LINE]	26 54 617
6	{180° / 3200 mil} − (5) = ANGLE A_3	5 45 383
7	OBSERVED ANGLE O_2	10 48 494
8	REPEAT (3)	14 49 185
		32 00 000
9	(7) + (8) [ENTER ON THIS LINE]	24 97 679
10	{180° / 3200 mil} − (9) = ANGLE B_1	7 02 321
11	1/2 OF (3)	7 24 592
12	LOG SIN (6)	9 707 7465
13	LOG SIN (7)	9 932 9634
14	LOG SIN (2)	9 899 5800
15	(12) + (13) + (14)	9 540 2899

GRUBER — CARLTON — BILL — JIM



16	LOG SIN (10)	9 803 5611	
17	LOG SIN (11)	9 685 5362	
18	LOG SIN (4)	9 966 5671	
19	(16) + (17) + (18)	9 455 6644	
30	IF (19) IS: MORE THAN (15) / LESS THAN (15); (20) IS: (19) − (15) / (15) − (19)	9 540 2899	
		0 084 6255	

31	ANGLE HAVING LOG TAN (30)	8 98 620
32	(21) − {45° / 800 mil}	8 00 000
		98 620
33	LOG TAN (22)	8 987 3249
34	LOG TAN (11)	9 935 4590
25	(23) + (34)	8 922 7839
26	REPEAT (11)	7 24 592
37	ANGLE HAVING LOG TAN (35)	85 070
38	(36) − (37)	6 39 522
29	(36) + (37)	8 09 662
30	REPEAT (28) OR (29), ANGLE A_1	8 09 662
31	REPEAT (6)	5 45 383
32	(30) + (31)	13 55 045

IF (19) IS: MORE THAN (15) / LESS THAN (15); (30) IS: (28) / (29); AND (24) IS: (29) / (28)

23	REPEAT (10)	7 02 321
34	REPEAT (29) OR (28), ANGLE B_3	6 39 522
35	(33) + (34)	13 41 843

TO LOCATE STATION Q

26	LOG GRID DISTANCE A TO B (FROM AUX COMP ON REV)	3 479 5655
37	LOG SIN (25)	9 985 8994
38	(36) + (37)	3 465 4649
39	REPEAT (13)	9 932 9634
40	(38) − (39) = LOG GRID DISTANCE A TO O	3 532 5015

TO LOCATE STATION R

41	LOG GRID DISTANCE A TO B (FROM AUX COMP ON REV)	3 479 5655
42	LOG SIN (34)	9 768 9369
43	(41) + (42)	3 248 5024
44	REPEAT (18)	9 966 5671
45	(43) − (44) = LOG GRID DISTANCE A TO R	3 281 9353

DATE 8-15-67

TO LOCATE STATION Q

REAR STATION B: CARLTON

AZ A TO B (FROM REV)	8 30 350
STA ANGLE REPEAT (30)	8 09 662
SUM	16 40 012
− 360° / 6400 mil	
AZIMUTH A TO Q	16 40 012
(+) 180° / 3200 mil	32 00 000
AZIMUTH Q TO A	48 40 012

AZ TO BEARING	
	32 00 000
	16 40 012
BEARING	15 59 99

REPEAT (40)	3.532 5015	REPEAT (40)	3.532 5015
LOG SIN BEARING	9.999 6649	LOG COS BEARING	8.594 0568
SUM = LOG dE	3.532 1664	SUM = LOG dN	2.126 5583

REPEAT (40)	3.532 5015	SUM = LOG dN	1.668 4796

STATION A	GRUBER	E 541 835.70	N 3 835 349.00	N 488.0
VERT ∠ O TO A WITH SIGN REVERSED	± 13 93	dE ⊕ 3 405.39	dN ⊖ 133.83	dN ⊖ 46.6
LOG TAN VERT ∠	8.135 9781			441.4
				* ⊕ 2.4
				443.8
				** − 0.8
STATION Q	JIM	E 545 241.09	N 3 835 215.17	N 443.0

TO LOCATE STATION R

REAR STATION B: CARLTON

AZ A TO B (FROM REV)	8 30 350
STA ANGLE REPEAT (32)	13 55 045
SUM	21 85 395
− 360° / 6400 mil	
AZIMUTH A TO R	21 85 395
(+) 180° / 3200 mil	32 00 000
AZIMUTH R TO A	53 85 395

AZ TO BEARING	
	32 00 000
	21 85 395
BEARING	10 14 60

REPEAT (45)	3.281 9353	REPEAT (45)	3.281 9353
LOG SIN BEARING	9.923 9416	LOG COS BEARING	9.735 2760
SUM = LOG dE	3.205 8769	SUM = LOG dN	3.017 2113

REPEAT (45)	3.281 9353	SUM = LOG dN	1.709 5647

STATION A	GRUBER	E 541 835.70	N 3 835 349.00	N 488.0
VERT ∠ R TO A WITH SIGN REVERSED	± 27.26	dE ⊕ 1 606.49	dN ⊖ 1 040.43	dN ⊖ 51.2
LOG TAN VERT ∠	8.427 6294			436.8
				* ⊕ 2.4
				439.2
				** − .3
STATION R	BILL	E 543 442.19	N 3 834 308.57	N 438.9

* DIFFERENCE IN HEIGHTS OF TARGET AND INSTRUMENT FROM GUIDE ON REVERSE

** CORRECTION FOR CURVATURE AND REFRACTION FROM TABLE ON REVERSE

COMPUTER: BAINES — CHECKER: BILBY — SHEET 1 OF 1 SHEETS

POST OAK — AREA — A-26-3 — NOTEBOOK REFERENCE

DA FORM 1 APR 56 6-18

PREVIOUS EDITIONS OF THIS FORM ARE OBSOLETE. THIS FORM TOGETHER WITH DA FORMS 6-2, 6-8 AND 6-19 REPLACES DA FORM 6-2a, 1 OCT 52, WHICH IS OBSOLETE.

Figure 10–28. Solution to illustrative two-point resection problem.

AUXILIARY COMPUTATION
AZIMUTH AND DISTANCE FROM A TO B

STATION	E COORDINATE	N COORDINATE	dE− dN+ / dE+ dN+
FROM STATION A	A 541 835.70	A 3 835 349.00	
TO STATION B	B 544 031.60	B 3 837 417.80	
IF A IS LESS THAN B REPEAT A	AA 541 835.70	AA 3 835 349.00	
IF AA IS BLANK, USE A-B, SIGN− IF AA IS FILLED, USE B-AA, SIGN+	dE + 2 195.90	dN + 2 068.80	dE− dN− / dE+ dN−

LOG dE	3.341 6126	ANGLE HAVING LOG TAN BEARING A TO B	8 30 35
LOG dN	3.315 7185	DETERMINE AZIMUTH FROM BEARING BY PLOTTING dE AND dN ON SKETCH AS GUIDE	
LOG dE − LOG dN = LOG TAN BEARING A TO B	0.025 8941	AZIMUTH A TO B [ENTER ON FRONT]	8 30 35

IF dE IS MORE THAN dN		IF dE IS LESS THAN dN	
REPEAT LOG dE	3.341 6126	REPEAT LOG dN	
LOG SIN BEARING A TO B	9.862 0471	LOG COS BEARING A TO B	
LOG dE − LOG SIN BEARING = LOG GRID DISTANCE A TO B	3.479 5655	LOG dN − LOG COS BEARING = LOG GRID DISTANCE A TO B	

[ENTER LOG GRID DISTANCE A TO B IN (36) AND/OR (41) ON FRONT]

TABLE - CORRECTION FOR CURVATURE AND REFRACTION

(NO INTERPOLATION NECESSARY FOR ARTILLERY SURVEY)

(SIGN ALWAYS MINUS)

Log Side (M)	Corr (M)	Log Side (M)	Corr (M)
3.079	.1	3.712	1.8
3.230	.2	3.736	2.0
3.322	.3	3.784	2.5
3.386	.4	3.824	3.0
3.435	.5	3.857	3.5
3.473	.6	3.886	4.0
3.508	.7	3.912	4.5
3.537	.8	3.934	5.0
3.562	.9	3.955	5.5
3.584	1.0	3.974	6.0
3.625	1.2	3.992	8.5
3.658	1.4	4.007	7.0
3.687	1.6		

GIVEN:

Coordinates of stations A and B.
Height of station A.

FIELD DATA:

Observe horizontal angles Q_1, Q_2, R_1, and R_2.
Observe vertical angle(s) from station(s) Q or (and) R to station A.
Measure height(s) of instrument(s) at station(s) Q or (and) R to nearest 0.1 meter.
Estimate height of target at station A, if not known.

GUIDE:

Enter observed field data in blocks marked [ ].
Find difference(s) between heights of instrument(s) and target as follows:

		STATION Q	STATION R
a	Known or Estimated Height of Target	+ 4.0	+ 4.0
b	Measured Height(s) of Instrument	− 1.6	− 1.6
c	Algebraic Sum a and b [Enter, with sign, in block(s) marked *]	⊕ − 2.4	⊕ − 2.4

Enter correction(s) for curvature and refraction in block(s) marked * *.

LIMITATIONS:

Angles A_1, A_2, B_1, B_2, Q_1, Q_2, R_1, and R_2 should be greater than 22 1/2° (400mils) or accuracy may fall below specifications

RESULTS:

Coordinates and height(s) of station(s) Q or (and) R.
Azimuth(s) from station(s) Q or (and) R to station A.

FORMULAS:

$$A_1 + B_2 = Q_1 + R_2$$

$$\text{Tan } Z = \frac{\text{Sin } A_2 \text{ Sin } Q_2 \text{ Sin } R_2}{\text{Sin } B_1 \text{ Sin } Q_1 \text{ Sin } R_1} \quad \text{or} \quad \text{Tan } Z = \frac{\text{Sin } B_1 \text{ Sin } Q_1 \text{ Sin } R_1}{\text{Sin } A_2 \text{ Sin } Q_2 \text{ Sin } R_2}$$

$$\text{Tan } \tfrac{1}{2}(A_1 - B_2) = \text{Tan } \tfrac{1}{2}(A_1 + B_2)\ \text{Tan}(Z - 45^\circ) \qquad \text{Tan } \tfrac{1}{2}(B_2 - A_1) = \text{Tan } \tfrac{1}{2}(A_1 + B_2)\ \text{Tan}(Z - 45^\circ)$$

$$AQ = \frac{AB \text{ Sin } (B_1 + B_2)}{\text{Sin } Q_2}$$

$$AR = \frac{AB \text{ Sin } B_2}{\text{Sin } R_1}$$

Z = an auxiliary angle required only in the computations (always between 45 and 90 degrees).

Figure 10–29. Solution to illustrative two-point resection problem.

(2) Entries required are the coordinates of the points A and B and the horizontal and vertical angles at points R and Q.

(3) The formulas to be used are shown on the back of the form.

10-23. Limitations and Use of Resection

Unless a resection (two or three point) has been checked by using another resection problem or by some other means of survey, it should not be used as a point from which to extend survey control. However, a battery center and the 01-02 target area base of field artillery battalion could be located by using a two-point or three-point resection. If known points are available, resection probably would allow the unit to conduct unobserved fire much sooner. If necessary, corrections could be made later by traversing to a known point. Resection could also be used to locate any single point, to check a location determined by some other means of survey, or to verify points of suspected known control.

CHAPTER 11
TRILATERATION

Section I. GENERAL

11–1. General

The introduction of electronic distance measuring devices has made possible the use of another method of survey known as Trilateration. This method employs the electronic measurement of the three sides of a triangle and the computation of the three interior angles. Since distance measuring devices require only an electronic line of sight, it is now possible to extend horizontal survey control over long distances and/or during periods of inclement weather, with certain limitations. Positions may be established within the 1:3,000 position closure specified in artillery fourth-order survey but azimuths determined in the trilateration scheme may be below the accuracy required for further extension of fourth-order control. For this reason, trilateration should be used only when triangulation or traverse cannot be feasibly conducted. In general, trilateration is more time consuming and complex than either traverse or triangulation, but its real merit lies in the fact that positions can be established by this method during periods when other methods would fail.

11–2. Employment

Trilateration may be employed to extend survey control to a forward area. The distances of the sides of the figure used may exceed the usable optical range of any theodolite, since optical lines of sight are not factors to be considered. This method of survey may also be employed to extend control over shorter distances when the optical line of sight is obscured due to bad weather. For field artillery use, a series of two or three (no more than three) strong quadrilaterals with measured diagonals, an electronic measurement of each side of the quad and both diagonals to a 1:25,000 comparative accuracy, and an azimuth on the base to a minimum considered accuracy of 0.15 mil is adequate to meet required field artillery accuracies.

a. Reconnaissance. The reconnaissance for a trilateration net consists of the selection of stations to ensure electronic lines of sight, consideration of the size and shape of the resulting triangles, the strength of figure factors, and the accessibility of stations either by vehicle, helicopter, or by foot.

b. Starting Control. Since trilateration normally is used during periods of non-intervisibility, the starting azimuth must be the azimuth of the starting base. There are four methods of determining this starting azimuth and length of base. They are as follows:

(1) The most desirable method is the use of two known stations established to a third-order or higher accuracy. The starting azimuth may be computed on a DA Form 6–1. The distance between the two known stations must be measured electronically rather than computed on DA Form 6–1 since it will be proportionately shorter or longer than the distance computed from coordinates and angular distortion can thus be minimized. A measurement taken from both directions on the base, with a comparative accuracy of 1:25,000 between the two measurements, will provide the base accuracy required.

(2) If a fourth-order or higher azimuth from a known fourth-order or higher survey control point to an accessible azimuth mark is known, and the station is in such a position that it may be used as one end of the starting base, then the distance from the known station to the azimuth mark is measured electronically and this distance and the known azimuth to the mark is used as the starting base.

(3) If only a single survey control point is known, then a point which is intervisible with the starting point must be selected and used as one end of the starting base. The distance to this known point must be measured electronically and the azimuth determined by astronomical observations or through the use of the azimuth gyro survey instrument to a minimum considered accuracy of 0.15 mil.

(4) If starting data is assumed for a station at one end of the base and the base electronically measured, the trilaterated data must be converted to the control of the next higher echelon as soon as fourth-order or higher control becomes available and an azimuth to a minimum considered accuracy of 0.15 mil on the starting base can be determined.

c. Permissible Figure. In triangulation, a check measured angles in a triangle is obtained by comparing the sum of the angles with 3,200 mils. While this check does not rule out the possibility of balancing errors, it is reasonable to assume that no gross blunders are involved. Such is not the case with trilateration. The sum of the computed angles in a trilaterated triangle will always equal 3,200 mils ± .02 mils (± .02 mils for round off) if no error in computation has been made. This means that in a chain of single triangles, there is not check on fieldwork for trilateration until a second known point is reached or an astro check is made. For this reason the highly desirable figure for trilateration is the quadrilateral, except in a limited time situation in which the single triangle chain may be necessary.

d. Extension Limits. Trilateration schemes may not be extended more than three quads or 30,000 meters, whichever comes first, without a position or directional check.

e. Azimuth Checks. When the reconnaissance for trilateration scheme is conducted, it must be remembered that azimuth checks for control of the scheme are essential. Therefore, when a trilateration scheme changes direction an appreciable amount (approx. 1,600 mils), the ends of the base for that specific quadrilateral must be intervisible. An astronomic observation or a gyro azimuth determination of the azimuth of the base is used to compare with the azimuth computed through the scheme. If the computed azimuth meets fourth-order traverse specifications (app B) upon comparison, the *observed* azimuth is then used for any further extension of direction. The two terminal points of the final figure in the scheme must also be intervisible so that the computed azimuth may be confirmed by comparison with an azimuth taken on this line by astronomic or gyroscopic methods. The trilateration scheme normally is measured during periods of inclement weather and the azimuth checks are performed when weather permits.

f. Side Length Limits. Errors in electronic distance measurements are not directly proportional to the distance. It can be expected that the absolute linear errors in 10,000 meter lines will be about the same as for 20,000 meter lines. If given the same absolute error, angles computed from long lines will be more accurate than those computed from short lines. For this reason, the minimum side of a trilateration figure is 5,000 meters.

g. Limits for Interior Angles. In order to be assured of a strong solution for the triangle, it is desirable to keep the interior angles between 533 mils and 2,133 mils whenever possible, but since such requirements usually result in loss of time, angles which lie between 400 mils and 2,400 mils are acceptable.

h. Elevation Limits. Distances determined using electronic measuring equipment are directly dependent on the elevation difference between stations of each end of the line. In most cases trilateration will be done when optical intervisibility between stations is non-existant and altimetry must be used to determine the difference in elevation between stations. When altimetry is used, the lengths of the lines should not exceed 20,000 meters and the elevation difference between stations at the ends of each line should not exceed 200 meters (para 12–6).

i. Weather Conditions. Electronically measured distances are directly affected by weather conditions. Altimetry is also directly affected by weather conditions (para 12–4), which in turn, affects the computation of the measured distance. Trilateration should not be attempted during unstable atmospheric conditions if maximum accuracy is desired.

j. Fieldwork. Side lengths measured with the DME's (MC–8) must be measured from both ends of the line. Side lengths measured with the Tellu-

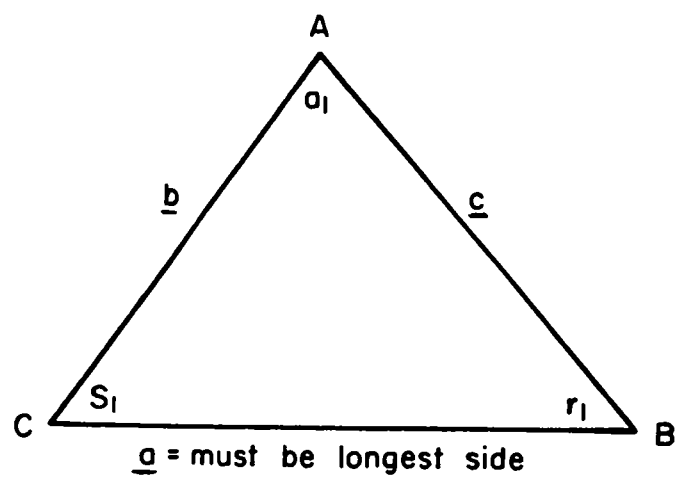


Figure 11–1. Trilateration.

rometer (MRA–1) must be measured with two coarse and four fine readings (app B). Prior to leaving the site, the recorder must compute the sea level distance. This distance must compare with the distance determined by the responder (DME) to a comparative accuracy of 1:25,000. If the tellurometer (MRA–1) is used, two individual measurements must be made and a comparative accuracy of 1:25,000 must be obtained between the two.

Section II. COMPUTATIONS

11–3. DA Form 6–7a

Both DA Form 6–7a (Computation—Plane Triangle) and DA Form 6–2 (Computation—Coordinates and Height From Azimuth, Distance and Vertical Angle) are used to compute trilateration problems. DA Form 6–7a is used for computation of plane triangles using the three measured sides. The front of the form has a space for a sketch of the triangle to be computed (fig 11–2). When entering data, the sides of the triangle must be entered so that the longest side corresponds to "a" in the diagram and all stations are in proper relationship. This provides for a more accurate solution for the value of angle q1. Angle q1 is used to solve for the values of angles r1 and s1. The angles are computed on lines 1 through 30. Lines 4 through 18 determine the value of angle q1 (cosine half-angle formula) angles s1 and r1 are determined using lines 19 through 24 and 25 through 30 respectively (Law of Sines); lines 31 through 34 afford a check on computations (this is *not* a check on fieldwork). On the back of the form (fig 11–3) are items of information giving guides, limitations, and formulas used.

11–4. Computations

a. DA Form 6–7a is used to compute angles from the measured distances. The angles are then used in conjunction with the side lengths to extend coordinate control on DA Forms 6–2. The triangle side lengths on DA Form 6–7a can be either UTM grid or sea level distance. Sea level distance must be converted to UTM grid distance by applying the log scale factor when computing coordinates on DA Form 6–2.

b. DA Form 6–2 is used to extend azimuth and compute coordinates.

c. Height is determined by altimetry.

d. To determine an accuracy ratio, a radial error $RE = eE^2 + eN^2$ is computed as for a traverse. Since the accuracy ratio could be computed using many combinations of sides, numerous values for the accuracy ratio would be possible. However, since the DA Form 6–2 is used to compute the trilateration scheme, the side lengths used to compute coordinates must also be used to compute the accuracy ratio.

The accuracy ratio $\left(AR = \frac{1}{\text{total distance} \div RE}\right)$ when computed using this route, must not be less than 1:3,000.

11–5. Illustrative Trilateration Problem (Use of DA Form 6–7a)

The lengths of the sides of the triangle measured with electronic distance measuring equipment are as follows:

a. Given:
side a = 9,127.07 meters
side b = 6,107.25 meters
side c = 8,973.53 meters

b. Requirement: Compute the value of angles q1, r1, and s1.

c. Solution: (fig 11–2).
q1 = 1,273.66 mils
r1 = 700.91 mils
s1 = 1,225.44 mils

11–6. Specifications

See appendix B, Trilateration.

11–7. Limitations

a. Extensive map and ground reconnaissance is required to ensure electronic line-of-sight and to insure that minimum distance angle requirements can be met from selected positions.

b. During periods of heavy rain or snow, atmospheric conditions will influence the measuring waves and increase the probable errors in the measured distances.

c. Angular error resulting from distance error makes it necessary to obtain directional checks from another source.

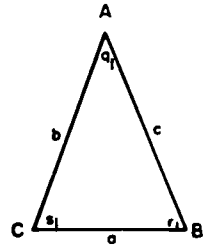
d. Vertical control must be carried (by means of altimeters) in order to reduce slope distances to sea level distances.

e. Quadrilateral figures must be used.

(1) Azimuth. The interior angles of triangles should be kept within the limits of 533 mils and

COMPUTATION — PLANE TRIANGLE
(Using Three Sides)

For use of this form, see FM 6-2; the proponent agency is the United States Continental Army Command.



REQUIRED DATA
(UTM grid or sea level distances of sides a, b and c.

OPTIONAL DATA
Plane UTM grid azimuth line a, b, or c.

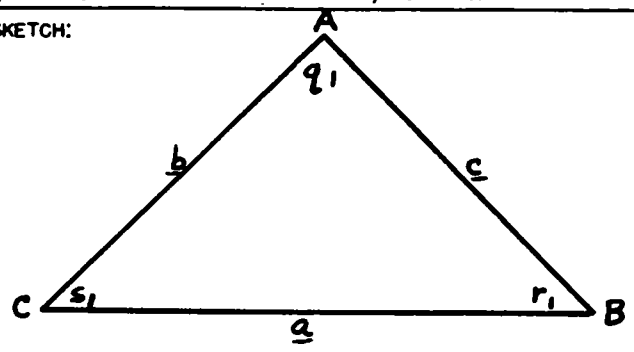
KNOWN AZIMUTH

TO = ____

Plane UTM grid coordinates station A, B, or C.
KNOWN COORDINATES

Sta. ____ E ____
N ____

SKETCH:



1	KNOWN LENGTH a	=	91 27 07	NOTE: Always use a as longest known side.			
2	KNOWN LENGTH b	=	61 07 25	19	(11)	=	3 785 8457
3	KNOWN LENGTH c	=	89 73 53	20	LOG SIN (18)	=	9 977 3187
4	(1) + (2) + (3)	=	242 07 85	21	(19) + (20)	=	3 763 1644
5	½ OF (4)	=	121 03 92	22	LOG (1)	=	3 960 3314
6	(1)	=	91 27 07	23	(21) — (22)	=	9 802 8330
7	(5) — (6)	=	29 76 85	24	ANGLE HAVING LOG SIN (23) = r_1	=	07 00 91
8	LOG (7)	=	3 473 7570	25	(13)	=	3 952 9633
9	LOG (5)	=	4 082 9260	26	(20)	=	9 977 3187
10	(8) + (9)	=	7 556 6830	27	(25) + (26)	=	3 930 2820
11	LOG (2)	=	3 785 8457	28	(22)	=	3 960 3314
12	(10) — (11)	=	3 770 8373	29	(27) — (28)	=	9 969 9506
13	LOG (3)	=	3 952 9633	30	ANGLE HAVING LOG SIN (29) = S_1	=	12 25 44
14	(12) — (13)	=	9 817 8740	PARTIAL PROOF			
15	10,000 0000 + (14)	=	19 817 8740	31	(18)	=	12 73 66
16	½ OF (15)	=	9 908 9370	32	(24)	=	07 00 91
17	ANGLE HAVING LOG COS (16)	=	06 36 83	33	(30)	=	12 25 44
18	2 X (17) = q_1	=	12 73 66	34	(31) + (32) + (33) = 180° / 3200ᵐ	=	32 00 01

REMARK

COMPUTER	CHECKER	DATE
PFC GEROLD	SGT KANDRA	27 JUL 19—

DA FORM 1 SEP 62 6-7a

REPLACES EDITION OF 1 OCT 52, WHICH IS OBSOLETE.

Figure 11-2. DA Form 6-7a.

GIVEN

FOR USE IN THIS COMPUTATION: UTM grid or sea level distances at sides a, b, and c.

FOR USE IN COMPUTATIONS LISTED IN "RESULTS": plane UTM grid azimuth of side a, b, or c; plane UTM grid coordinates of station A, B, or C.

OBSERVE

No observing required.

GUIDE

Proceed with computation as indicated.

Sum of length of two sides must be greater than longest side.

If it is desired to determine log sin, cos, or tan of angle more than 90 or 1600‰, substitute 180 or 3200‰ minus the angle and proceed with computation.

LIMITATIONS

This computation is for use by artillery units and should not be used when accuracies greater than 1 part in 5,000 are required.

This computation should not be used to establish survey control stations more than 30 miles distant from stations of origin.

The proof checks part of the computation only, and is not an absolute check on the computation.

RESULTS

Three side and three angles of the triangle are now known. This data may be used with DA Form 6-2 (Computation Coordinates from Azimuth and Distance) under the following conditions:

(a) When UTM grid distances are used, the log scale factor will not be used.

(b) When sea-level distances are used, the log scale factor must be used.

FORMULA

$$\cos \frac{1}{2} q_1 = \sqrt{\frac{\left(\frac{a+b+c}{2}\right)\left[\left(\frac{a+b+c}{2}\right)-a\right]}{bc}}$$

Figure 11-3. Reverse, DA Form 6-7a.

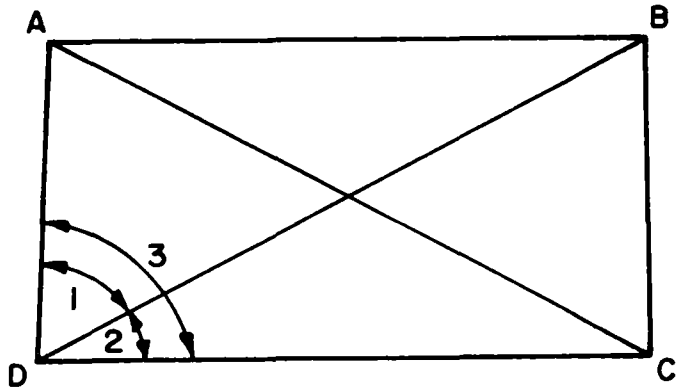


Figure 11–4. Interior angles.

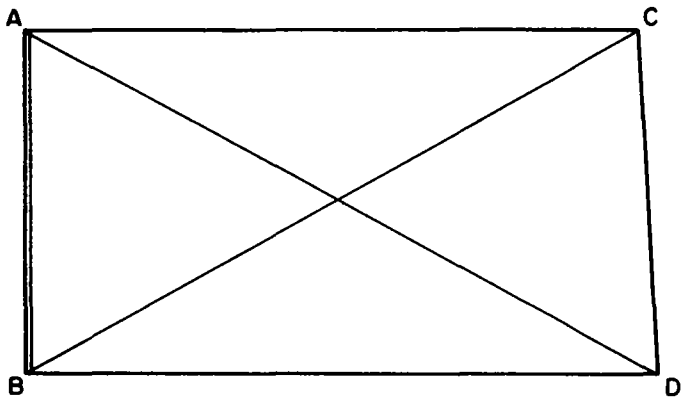


Figure 11–5. Quadrilateral.

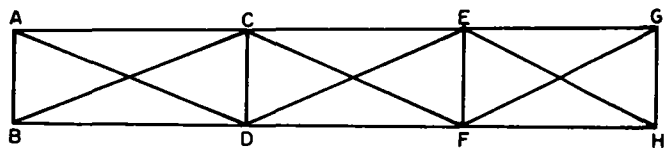


Figure 11–6. Trilateration.

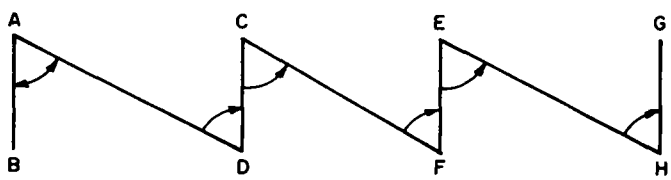
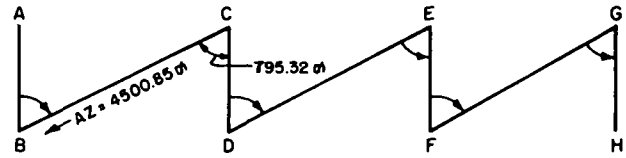


Figure 11–7. Route 1.

2,133 mils although the limits of 400 mils and 2,400 mils are accepted if time is critical. After the angles are computed, they must be checked. In a quad, each station will have three computed angles (fig 11–4). The sum of the two small angles must equal the large angle within .2 mil.

Although this may seem excessive, it must be remembered that excessive angular errors may be obtained even when position is good. These angles



AZ. C to B = 4500.85 mil
Angle BCD = -795.32 mil
AZ. C to D = 3705.53 mil

Figure 11–8. Route 2.

are then used on DA Form 6–2. Azimuths determined by trilateration means must not be used for further extension of survey control unless confirmed by astronomic or gyroscopic azimuth determination.

(2) *Coordinates.* In a quadrilateral scheme, there are optional routes for computation. To compute the coordinates (fig 11–5) of points D from azimuth and distance, side DB and angle ABD or side AD and angle BAD, may be used. Likewise, coordinates of point C may be computed from azimuth and distance based on side AC and angle CAB, or side BD and angle ABC. There are several possible selections for computing a quad scheme. As with triangulation, there is a best route to use, but selection is not made by using R1 chain factors. For field artillery purposes, the following method is considered best. In figure 11–6 there are two routes which may be used to compute all unknown points in the scheme (fig 11–7 and 11–8).

The route selected should contain the greater number of angles nearest the 1,000 mil value.
Either of these routes form a traverse which may be computed on DA Form 6–2. However, the azimuth position of DA Form 6–2 must be modified as indicated below. Interior angles shown in fig 11–7 or fig 11–8 become the station angles for the traverse. Extreme care must be taken when computing "azimuth to forward station" on DA Form 6–2. [i.e., the azimuth from C to B (fig 11–8), when computed, was found to be 4,500.85 mils. The computed angle DCB (from DA Form 6–7a is 795.32 mils. For the purpose of azimuth, angle DCB must be considered a counter-clockwise angle and must be subtracted from the azimuth C to B to determine azimuth C to D].

Az C to B = 4,500.85 mil.
Angle BCD = −795.32 mil.
Az C to D = 3,705.53 mil.

In some instances, these interior angles will be added and in other cases they will be subtracted from azimuth to rear station to determine azimuth to forward station on DA form 6–2.

CHAPTER 12
ALTIMETRY

Section I. GENERAL

12–1. General

a. The surveying altimeter is used in artillery survey to determine height when stations are not optically intervisible. Although altimetry is not considered a precise method for determining heights during normal weather conditions it is sufficiently accurate for artillery survey purposes. The altimeter is used to determine the difference in height between two stations (one of known height and one of unknown height). This difference is then applied to the height of the known station to determine the height of the unknown station. Use of the electronic distance measuring equipment in conjunction with trilateration establishes a definite need for altimetry.

b. The basic principle of altimetry is that the pressure caused by the weight of the column of air above the observer decreases as the observer rises in altitude. The relationship between pressure and altitude is not constant since air is compressible. Furthermore, changes in air density caused by variations in temperature, relative humidity, and gravity will change the pressure versus altitude ratio.

c. In order to eliminate the need for converting pressure readings to altitude, the altimeter described herein is calibrated in meters. However, to calibrate an altimeter a standard pressure-altitude relationship must be used. Because altitude does not have a constant relationship to pressure, the altimeter can be used only to measure differences in elevation with respect to some known station.

d. The pressure-altitude relationship holds good only for certain standard conditions. If these conditions do not exist while a survey is being made, then corrections must be applied. Air temperature and relative humidity have the greatest effect on the density of the air and are therefore the most significant variables.

e. The instrument temperature can also affect the altimeter reading if it is different from the 75° F at which the instrument was calibrated. The air temperature mentioned in *d* above must not be confused with this instrument temperature. The altimeters are calibrated so that the error caused by a difference in temperature is small. However, when maximum accuracy is desired, the instrument temperature correction should be applied.

f. Barometric pressure changes will affect the altimeter just as altitude changes do. Since the atmosphere is continually changing, it is necessary to take pressure changes into consideration. The success with which pressure changes are evaluated will determine the accuracy of the altimeter survey. During inclement weather and when there are high, gusty winds, the unstable atmospheric conditions cause altimetry to yield inaccurate results.

g. If reasonable precautions are observed, a majority of the elevations will be found correct within plus or minus three meters. The maximum error will seldom exceed five meters.

12–2. Surveying Altimeter

a. The surveying altimeter is an aneroid type altimeter weighing approximately nine pounds, designed for use up to 4,500 meters above and 300 meters below mean sea level (fig 12–1). This instrument measures atmospheric pressure by mechanical means. The scales on the altimeter are so graduated that air pressure is indicated in units of height (meters). The instrument contains an aneroid element consisting of a single vacuum chamber. Expansion or contraction of this chamber is indicated by the rotation of an indicating hand and the movement of the revolution indicator.

b. The altimeter has a circular dial with four scales, two outer scales and two inner scales (fig 12–2). All graduations are black and are numbered every 50 meters. Each scale covers approximately one-fourth of the range. Since the pointer makes four revolutions to cover the entire range, a

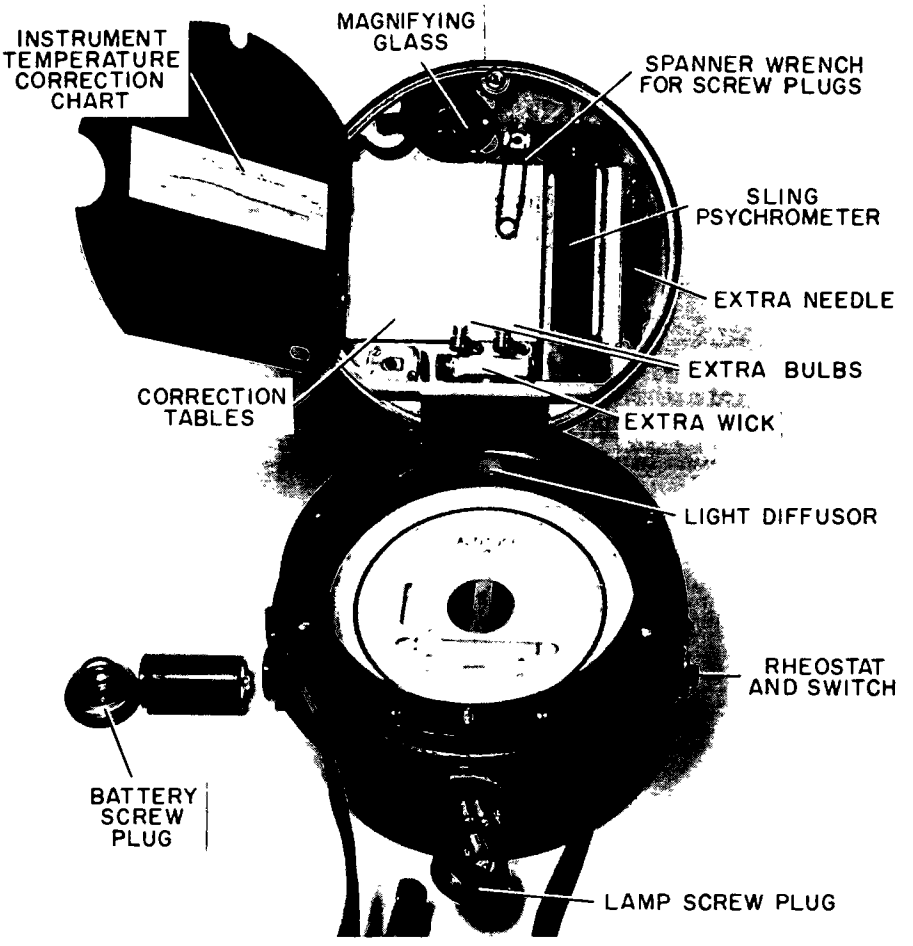


Figure 12–1. Surveying altimeter, 4,500 meter, 2-meter divisions.

revolution indicator is provided so that the observer can determine upon which scale the instrument is operating. The scales are calibrated to intervals of 2 meters. The zero on the dial corresponds to a pressure-height of 300 meters below mean sea level under standard conditions; 4,800 on the dial corresponds to 4,500 meters above mean sea level under standard conditions. An annular mirror (fig 12–2) located in the dial between the outer and inner scales, is provided so that reading parallax may be eliminated by superimposing the pointer on its reflected image. Each altimeter dial is custom calibrated for the vacuum chamber and mechanical linkage with which it is to be used. For this reason, the dial, the vacuum chamber, all parts of the mechanical linkage and the instrument temperature correction chart are not interchangeable with corresponding parts of other altimeters. In the face of the dial is a desiccant condition indicator which becomes pink when moisture within the case is excessive.

c. The altimeter is housed in an aluminum case, 21.5 centimeters in diameter by 16 centimeters deep. Rubber shock mounts protect the instrument from injury. For travel or shipping through humid areas, it can be made airtight by closing all threaded caps. The case contains a small vent which permits the pressure inside the case to become equal to that on the outside. The vent is normally left open; however, it should be closed when the instrument is packed for shipping. A built-in night lighting system utilizes standard flashlight batteries and lamps. Scale lighting is controlled by a switch and rheostat assembly. Batteries should be placed in the case only for night operations and promptly removed after use. A silica gel desiccant is in a container in the lower part of the case. The altimeter lid holds the folding sling psychrometer assembly, the correction and calibration charts, a reading glass, spare pointer, spare lamps, a spanner wrench, and spare wicks for the psychrometer.

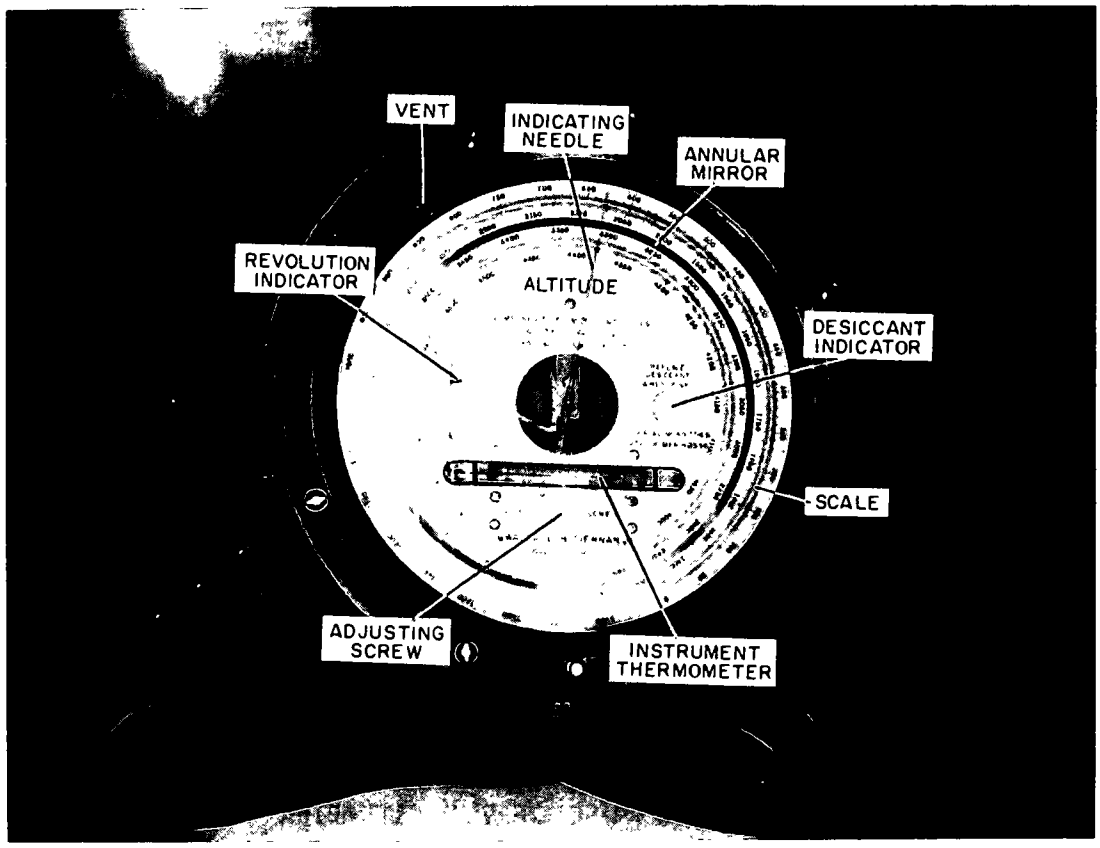


Figure 12-2. Altimeter dial.

12-3. Sling Psychrometer

a. The psychrometer is a two-thermometer (mounted side by side) device used to determine relative humidity. One thermometer bulb, covered with a wick, is thoroughly moistened with water. The other thermometer bulb is kept dry. In the sling psychrometer, the two thermometers are whirled rapidly in the air (about 120 revolutions per minute for at least one minute) to force air past both bulbs. The dry bulb will not be affected by the air movement, whereas the water evaporating from the wick will drop the wet bulb temperature in proportion to the humidity in the atmosphere. The two thermometers (wet bulb first) are read immediately after the whirling stops before the air temperature has a chance to affect the readings. Several readings should be made to make sure the lowest stable temperature is reached. (If the weather is below 32°F, only a dry bulb reading is taken and the correction factor is determined from this reading).

b. The thermometers should be checked against a standard thermometer or against each other. When this check is made, the wet bulb reading must be made with a dry wick. A correction factor is determined for any thermometer that does not agree within 2° of the standard or other thermometers. This correction factor will be recorded in the instrument case and will be applied to all field data determined by the psychrometer.

12-4. Weather Conditions

Barometric pressure is continually changing due to the movement of air masses over the world. This pressure change causes fluctuation in the altimeter readings even when set up on one point. The extent to which this fluctuation can be observed and evaluated determines the accuracy of the readings. Since direct sunlight can create uneven heating within the instrument, and therefore, inaccurate readings, the altimeter is always set in the shade or is shaded during the operation. During unstable weather conditions and periods of high gusty winds, pressure changes are very erratic, and an altimeter survey during these times will yield inaccurate results. In general, the best results are obtained when windspeeds are less

than 10 miles per hour. Altimetry should not be attempted when wind velocity exceeds 15 miles per hour. In general, the early morning hours between 0600 and 0900 hours, and the early evening hours between 1600 and 2000 hours afford the most stable pressure conditions. However, excellent results have been obtained up to 2400 hours and later. The atmospheric conditions that prevail during fog, mist or light rain are usually suitable for altimetric leveling.

12–5. Care and Maintenance

a. The surveying altimeter is a delicate instrument although rugged enough to be used for field survey if handled with care and protected from shock. The instrument and its accessories should be kept clean and dry. The window of the instrument is made of clear plastic, which scratches easily. It should be brushed with a camelhair brush to remove dust and polished with lens tissue or a soft rag. The instrument should *not be oiled.* Oil will interfere with the operation of the instrument and cause erroneous readings.

b. Field artillery personnel are not authorized to repair the instrument. They should never remove the window. The spare hand which is issued with the instrument should be replaced by engineer instrument repair personnel if replacement is necessary.

c. Field artillery survey personnel are authorized to remove and dry or replace the silica gel desiccant in the instrument when the desiccant condition indicator turns pink. The silica gel can be dried by heating it to 300°F for at least 10 minutes. To replace the desiccant, unscrew the cap in the side of the case and remove the desiccant from the tube. Replace desiccant in reverse order.

d. Field artillery survey personnel are authorized to replace the lamp and to insert and remove the batteries for the night-lighting system. The batteries should not be inserted until the instrument is to be used at night, and should always be removed after use.

e. Field artillery survey personnel are authorized to replace broken thermometers in the sling psychrometer. Thermometers can be replaced by removing the screw cap from the end of the psychrometer head. The cork disc for the cap must be in place when the cap is replaced.

Section II. USE OF THE ALTIMETER

12–6. Methods of Altimetry

a. Two methods of altimetry are employed in field artillery survey. These methods are—

(1) The leapfrog method (para 12–13) is of primary interest to the field artillery since this method is particularly suited for use in conjunction with a method of survey called trilateration (chap 11).

(2) The single-base method (para 12–16) is of secondary interest to the field artillery but may be used in special situations.

b. Both methods of altimetry employ a base station and field stations. A base station is a station or point of known height; a field station is a station for which the height is to be determined.

c. Both methods of altimetry require simultaneous readings of the altimeter scales at the base station and at the field station(s). These simultaneous scale readings, corrected and adjusted for differences in instruments, are compared to determine the indicated differences in height. The wet and dry bulb temperatures, made at the base station at the time of the simultaneous readings, are used as arguments to determine the correction factor from the air temperature and relative humidity correction chart (fig 12–3). This correction is applied to the difference in the adjusted scale readings to obtain the corrected difference in height between stations.

d. The field station and base station make simultaneous readings by coordinating the time by radio communication or by using a prearranged observing schedule. Consequently, the field station observer and the base station observer must synchronize their watches.

e. During normal weather conditions, a majority of the heights determined by altimetry will be correct within 3 meters, and the maximum error will seldom exceed 5 meters, provided the following precautions are taken:

(1) Temperature correction is applied to the individual instrument.

(2) Comparison adjustment is made.

(3) Air temperature and relative humidity correction factor is applied.

(4) Difference in height between the base station and any field station is less than 200 meters.

(5) Distance between the base station and any field station is less than 20,000 meters.

TABLE I

AIR TEMPERATURE & RELATIVE HUMIDITY CORRECTION FACTOR FOR ALTITUDE

Temperature Below Freezing			Wet Bulb Temperature Degrees F.																		
			32	34	35	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	
Deg. F.	Factor	32	0.967																		32
-65	0.772	34	0.971	0.971																	34
-60	0.782	36	0.974	0.975	0 975																36
-55	0.792	38	0.978	0.978	0.979	0.979															38
-50	0.802	40	0.982	0.982	0.983	0.983	0.984														40
-45	0.812	42	0.985	0.986	0.986	0.987	0.987	0.988													42
-40	0.822	44	0.989	0.989	0.990	0.990	0.991	0.991	0.992												44
-38	0.826	46	0.992	0.993	0.993	0.994	0.995	0.995	0.996	0.996											46
-36	0.830	48	0.996	0.997	0.997	0.998	0.998	0.999	0.999	1.000	1.000										48
-34	0.834	50	1.000	1.000	1.001	1.001	1.002	1.002	1.003	1.003	1.004	1.005									50
-32	0.838	52	1.003	1.004	1.004	1.005	1.005	1.006	1.006	1.007	1.008	1.008	1.009								52
-30	0.842	54	1.007	1.008	1.008	1.008	1.009	1.010	1.010	1.011	1.011	1.012	1.012	1.013							54
-28	0.846	56	1.011	1.011	1.012	1.012	1.013	1.013	1.014	1.014	1.015	1.016	1.016	1.017	1.017						56
-26	0.850	58	1.014	1.015	1.015	1.016	1.017	1.017	1.018	1.018	1.019	1.019	1.020	1.020	1.021	1.022					58
-24	0.854	60	1.018	1.019	1.019	1.020	1.020	1.021	1.021	1.022	1.022	1.023	1.024	1.024	1.025	1.026	1.026				60
-22	0.858	62	1.022	1.022	1.023	1.023	1.024	1.024	1.025	1.025	1.026	1.027	1.027	1.028	1.028	1.029	1.030	1.031			62
-20	0.862	64	1.026	1.026	1.027	1.027	1.027	1.028	1.028	1.029	1.030	1.030	1.031	1.032	1.032	1.033	1.034	1.034	1.035		64
-18	0.866	66		1.030	1.030	1.031	1.031	1.032	1.032	1.033	1.033	1.034	1.034	1.035	1.036	1.037	1.037	1.038	1.039	1.040	66
-16	0.870	68		1.033	1.034	1.034	1.035	1.035	1.036	1.036	1.037	1.038	1.038	1.039	1.040	1.040	1.041	1.042	1.043	1.043	68
-14	0.874	70			1.037	1.038	1.038	1.039	1.039	1.040	1.041	1.041	1.042	1.043	1.043	1.044	1.045	1.046	1.046	1.047	70
-12	0.878	72			1.041	1.042	1.042	1.042	1.043	1.044	1.044	1.045	1.046	1.046	1.047	1.048	1.048	1.049	1.050	1.051	72
-10	0.882	74				1.045	1.046	1.046	1.047	1.047	1.048	1.049	1.049	1.050	1.051	1.051	1.052	1.053	1.054	1.054	74
- 8	0.886	76				1.049	1.049	1.050	1.050	1.051	1.052	1.052	1.053	1.054	1.054	1.055	1.056	1.057	1.057	1.058	76
- 6	0.890	78					1.053	1.054	1.054	1.055	1.055	1.056	1.057	1.057	1.058	1.058	1.059	1.060	1.061	1.062	78
- 4	0.894	80					1.057	1.057	1.058	1.058	1.059	1.060	1.060	1.061	1.062	1.062	1.063	1.064	1.065	1.065	80
- 2	0.898	82						1.061	1.061	1.062	1.063	1.063	1.064	1.065	1.065	1.066	1.067	1.067	1.068	1.069	82
0	0.902	84						1.064	1.065	1.066	1.066	1.067	1.068	1.068	1.069	1.070	1.070	1.071	1.072	1.073	84
2	0.906	86							1.069	1.069	1.070	1.071	1.071	1.072	1.073	1.073	1.074	1.075	1.076	1.076	86
4	0.910	88							1.072	1.073	1.073	1.074	1.075	1.075	1.076	1.077	1.078	1.078	1.079	1.080	88
6	0.914	90								1.076	1.077	1.078	1.078	1.079	1.080	1.081	1.081	1.082	1.083	1.084	90
8	0.919	92								1.080	1.081	1.081	1.082	1.083	1.084	1.084	1.085	1.086	1.087	1.087	92
10	0.923	94									1.084	1.085	1.086	1.087	1.087	1.088	1.089	1.089	1.090	1.091	94
12	0.927	96									1.088	1.089	1.090	1.090	1.091	1.092	1.092	1.093	1.094	1.095	96
14	0.931	98										1.093	1.093	1.094	1.095	1.095	1.096	1.097	1.097	1.098	98
16	0.935	100										1.096	1.097	1.097	1.098	1.099	1.100	1.100	1.101	1.102	100
18	0.939	102											1.100	1.101	1.102	1.102	1.103	1.104	1.105	1.106	102
20	0.943	104											1.104	1.105	1.105	1.106	1.107	1.108	1.108	1.109	104
22	0.947	106												1.108	1.109	1.110	1.111	1.111	1.112	1.113	106
24	0.951	108												1.112	1.113	1.113	1.114	1.115	1.116	1.117	108
26	0.955	110													1.116	1.117	1.118	1.119	1.119	1.120	110
28	0.959	112													1.120	1.121	1.122	1.122	1.123	1.124	112
30	0.963	114														1.125	1.125	1.126	1.127	1.128	114
			32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	

This chart is to be used to obtain the temperature and relative humidity corrections required when using the single-base method of altimeter leveling. Use only with altimeters set and calibrated in meters according to the Smithsonian Meteorological Table No. 51.

Dry Bulb Temperature Degrees F.

Dry Bulb Temperature Degrees F.

EXAMPLE OF USE OF CHART

Assume altimeter "A" reads 900 meters and "B" reads 1100 meters, dry bulb 80°F, wet bulb 60°F. Find 80 in dry bulb temperature column, follow across to 60 of wet bulb temperature column. Read correction factor 1.063. Corrected altitude difference = (1100-900) (1.063) = 212.6 meters. Interpolate the correction factor to the nearest .001.

(continued on facing page)

Figure 12–3. Temperature and relative humidity chart.

f. Tables II and III, Tabulated Correction Factors for Latitude and Altitude, are contained in the lid of the altimeter. Since these factors are insignificant for field artillery purposes, these tables are not used.

12–7. Reading Altimeter Scales

The procedure for reading the scales of the altimeter is as follows:

a. Place the instrument as nearly level as possible with the dial in the horizontal position. The

TABLE I (continued)

AIR TEMPERATURE & RELATIVE HUMIDITY CORRECTION FACTOR FOR ALTITUDE

Dry Bulb Temperature Degrees F.	Wet Bulb Temperature Degrees F.																						
	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110	
68	1.046																						68
70	1.048	1.049																					70
72	1.052	1.052	1.053																				72
74	1.055	1.056	1.057	1.058																			74
76	1.059	1.060	1.061	1.062	1.063																		76
78	1.063	1.063	1.064	1.065	1.066	1.067																	78
80	1.066	1.067	1.068	1.069	1.070	1.071	1.072																80
82	1.070	1.071	1.072	1.073	1.074	1.075	1.076	1.077															82
84	1.074	1.074	1.075	1.076	1.077	1.078	1.080	1.081	1.082														84
86	1.077	1.078	1.079	1.080	1.081	1.082	1.083	1.084	1.086	1.087													86
88	1.081	1.082	1.083	1.084	1.085	1.086	1.087	1.088	1.089	1.091	1.092												88
90	1.085	1.085	1.086	1.087	1.088	1.090	1.091	1.092	1.093	1.094	1.096	1.097											90
92	1.088	1.089	1.090	1.091	1.092	1.093	1.094	1.096	1.097	1.098	1.099	1.101	1.102										92
94	1.092	1.093	1.094	1.095	1.096	1.097	1.098	1.099	1.100	1.102	1.103	1.104	1.106	1.107									94
96	1.096	1.096	1.097	1.098	1.099	1.101	1.102	1.103	1.104	1.105	1.107	1.108	1.109	1.111	1.112								96
98	1.100	1.100	1.101	1.102	1.103	1.104	1.105	1.107	1.108	1.109	1.110	1.112	1.113	1.115	1.116	1.118							98
100	1.103	1.104	1.105	1.106	1.107	1.108	1.109	1.110	1.111	1.113	1.114	1.115	1.117	1.118	1.120	1.122	1.123						100
102	1.106	1.107	1.108	1.109	1.110	1.112	1.113	1.114	1.115	1.116	1.118	1.119	1.120	1.122	1.124	1.125	1.127	1.128					102
104	1.110	1.111	1.112	1.113	1.114	1.115	1.116	1.118	1.119	1.120	1.121	1.123	1.124	1.126	1.127	1.129	1.130	1.132	1.134				104
106	1.114	1.115	1.116	1.117	1.118	1.119	1.120	1.121	1.122	1.124	1.125	1.126	1.128	1.129	1.131	1.132	1.134	1.136	1.137	1.139			106
108	1.118	1.118	1.119	1.120	1.121	1.123	1.124	1.125	1.126	1.127	1.129	1.130	1.131	1.133	1.135	1.136	1.138	1.139	1.141	1.143	1.144		108
110	1.121	1.122	1.123	1.124	1.125	1.127	1.127	1.128	1.130	1.131	1.132	1.134	1.135	1.137	1.138	1.140	1.142	1.143	1.145	1.146	1.148	1.150	110
112	1.125	1.126	1.127	1.128	1.129	1.130	1.131	1.132	1.133	1.135	1.136	1.137	1.139	1.140	1.142	1.144	1.145	1.147	1.148	1.150	1.152	1.153	112
114	1.129	1.129	1.130	1.131	1.132	1.133	1.135	1.136	1.137	1.138	1.140	1.141	1.142	1.144	1.145	1.147	1.149	1.151	1.152	1.154	1.156	1.157	114
116	1.132	1.133	1.134	1.135	1.136	1.137	1.138	1.139	1.141	1.142	1.143	1.145	1.146	1.148	1.149	1.151	1.153	1.154	1.156	1.158	1.159	1.161	116
118	1.136	1.137	1.138	1.139	1.140	1.141	1.142	1.143	1.144	1.146	1.147	1.148	1.150	1.151	1.153	1.154	1.156	1.158	1.160	1.161	1.163	1.165	118
120	1.139	1.140	1.141	1.142	1.143	1.144	1.146	1.147	1.148	1.149	1.151	1.152	1.153	1.155	1.156	1.158	1.160	1.162	1.164	1.165	1.167	1.169	120
122	1.143	1.144	1.145	1.146	1.147	1.148	1.149	1.150	1.151	1.152	1.154	1.156	1.157	1.159	1.160	1.162	1.164	1.166	1.167	1.169	1.171	1.173	122
124	1.147	1.148	1.149	1.150	1.151	1.152	1.153	1.154	1.155	1.157	1.158	1.159	1.161	1.162	1.164	1.166	1.167	1.169	1.171	1.172	1.174	1.176	124
126	1.150	1.151	1.152	1.153	1.154	1.155	1.157	1.158	1.159	1.160	1.162	1.163	1.164	1.166	1.168	1.169	1.171	1.173	1.174	1.176	1.178	1.180	126
	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110	

Figure 12-8—Continued.

instrument must be protected from the sun and wind.

b. Tap the window of the instrument lightly to overcome any lag caused by static electricity.

c. Position the eye above the dial so that the indicating hand and its reflection in the annular mirror coincide. (Care must be taken to select the reflection of the hand and not its shadow). This step eliminates parallax in reading the scales.

d. Determine the scale to be read by noting the position of the revolution indicator.

e. Read the proper scale under the indicating hand by visual interpolation to the nearest 0.5 meter. The reading glass is used to facilitate reading the scale. Care must be taken to insure that the correct scale is read, since the scales are numbered concentrically and increase in value in a counterclockwise direction.

12–8. Corrections and Adjustments

a. The temperature correction for the individual instrument should be applied to the scale reading of each instrument (para 12–9). The application of this correction provides the *corrected scale reading.*

b. The comparison adjustment should be applied to the corrected scale reading of the field station instrument (para 12–10). The application of this adjustment provides the *adjusted scale reading.*

c. The difference between the corrected scale reading of the base station and the adjusted scale reading of the field station should be corrected for air temperature and relative humidity (para 12–11) to obtain corrected difference in height between stations.

12–9. Individual Instrument Temperature Correction

a. Each surveying altimeter is calibrated at a temperature of 75° F. An instrument temperature other than 75° will change the value of the scale reading, and a correction must be made for the difference.

b. A mercury alloy thermometer is mounted in the dial of each altimeter and is used to determine the individual instrument temperature each time a scale reading is made. The correction for instrument temperature is determined from the instrument temperature correction chart fastened in the lid of each instrument.

This chart is different for each instrument. Figure 12–4 illustrates the temperature correction chart for one instrument. To obtain the correction which should be applied to an instrument reading:

(1) Locate the position along the bottom of the graph which corresponds to the scale reading, taken to the nearest 100 meters.

(2) Project this point upward along the vertical line of the graph to the curved line of the graph.

(3) From the point of the intersection of the projected line and the curved line, project a second line to the left, parallel to the horizontal lines on the graph.

(4) At the intersection of the projected horizontal line with the left side of the graph, determine the meters correction per degree Fahrenheit, noting the sign of the correction.

(5) Multiply this factor by the difference between the instrument temperature at which the scale reading was taken and 75° F. (The sign of the product is the sign of the correction.)

(6) Apply this value to the altimeter scale

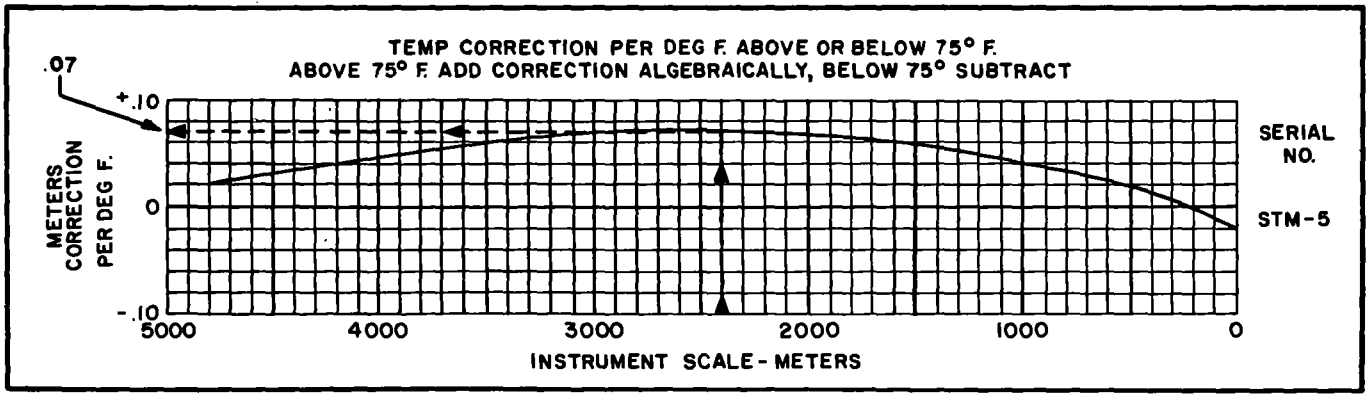


Figure 12–4. Instrument temperature correction chart.

reading. If the instrument temperature was above 75° F add the value algebraically. If the instrument temperature was below 75° F, subtract the value algebraically. This correction provides the corrected scale reading.

c. The following example illustrates the application of an individual instrument temperature correction:

(1) 2431.5 (scale reading).

(2) 50° F (instrument temperature).

(3) 75° — 50° = 25° (number of degrees to which correction is to be applied).

(4) +0.07 meters (correction per degree) (from correction chart fig 12–4).

(5) 25 x 0.07m = 1.75 meters (correction to be applied).

(6) 2431.5 — (+1.8) = 2429.7 (corrected scale reading).

12–10. Comparison Adjustment

a. The base station instrument is placed at a station of known height. The field station altimeter is placed beside the base station instrument at the same height. The initial comparison is made by taking simultaneous readings of the two altimeters and recording in the field notebook the time, instrument temperature, and scale reading for each. The data for each station instrument is recorded in a field notebook located at each station. In addition, for comparison purposes, the corrected scale readings for both the base station and the field station are recorded in the field station field notebook (fig 12–6 and 12–7).

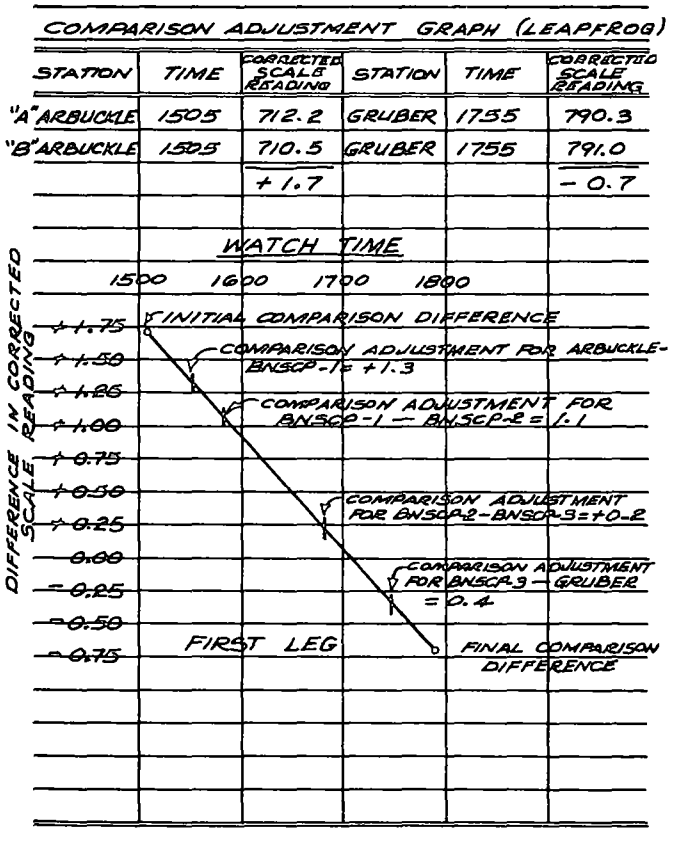


Figure 12–5. Comparison adjustment graph.

b. After the field survey is completed, the final comparison is made and recorded in the same manner as the initial comparison.

c. The time lapse between the initial comparison and the final comparison should be held to a minimum, less than 4 hours if possible.

d. If the initial comparison agrees with the final comparison, then the comparison adjustment is considered standard for all altimeter readings taken in between. If the initial and final comparisons do not agree, then a comparison adjustment graph must be constructed to determine the adjustment for intermediate stations (fig 12–5). The procedures for preparing and using the graph are as follows:

(1) Set up the graph by assigning time values to the vertical lines in the field station field notebook, to include the observing period from initial to final comparisons.

(2) Assign "difference in corrected scale readings" values to the horizontal lines, to include the difference between the initial and final comparisons.

(3) Use initial watch time and the differences in the corrected scale readings to plot the initial comparison point on the graphs.

(4) Use final watch time and the difference in the corrected scale readings to plot the final comparison point on the graph.

(5) Join the two points with a straight line.

(6) Using the watch time for each intermediate station occupied by the field station instrument as the argument, read the comparison adjustment for that station from the left side of the graph.

(7) Then enter the comparison adjustment in the appropriate column of the field station field notebook (opposite the time observed) and apply the comparison adjustment algebraically to the corrected scale reading to determine the adjusted scale reading for the station of interest.

12–11. Correction for Air Temperature and Relative Humidity

a. Because the pressure exerted by a column of

"A" ALTIMETER (BASE)

NO WIND
WEATHER: OVERCAST — CHIEF-OF-PARTY: Sgt. Brown

DESIGNATION ALTIMETRY LEAPFROG DATE 2 AUGUST 1967 — INSTR. NO.: # 7716 — OBSERVER: PFC. Wright

STATION	TIME	INSTR. TEMP.	SCALE READING	INSTR. TEMP. CORR.	CORR. SCALE READING	TEMPERATURE DRY	TEMPERATURE WET		REMARKS		
ARBUCKLE	1505	81	712.0	+0.2	712.2						
ARBUCKLE	1630	82	712.5	+0.2	712.7	88	76				
BNSCP-2	1550	85	688.0	+0.3	688.3	89	77				
BNSCP-2	1650	88	687.5	+0.4	687.9	90	77				
GRUBER	1730	86	790.0	+0.3	790.3	89	76				
GRUBER	1755	86	790.0	+0.3	790.3						
1	2	3	4	5	6	7	8				
Column 1	Station at which "A" Altimeter reading is taken.										
" 2	Time of observation.										
" 3	Instrument temperature.										
" 4	"A" Altimeter scale reading.										
" 5	Instrument temperature correction (see para. 12-9)										
" 6	Corrected scale reading, algebraic sum of column 4 and 5.										
" 7	Dry bulb temperature (see para. 12-3)										
" 8	Wet bulb temperature (see para. 12-3)										

Figure 12-6. Altimeter "A" recorder's notes for altimetry (modified leapfrog).

air is affected by changes in temperature and relative humidity, a correction factor must be applied to the difference in height between stations. The correction factor can be obtained by making a psychrometer reading (para 12-3) each time a scale reading is made by the base station altimeter (except comparison readings) and recording the wet and dry bulb temperatures in the base station field notebook opposite the scale reading (fig 12-6).

b. If the wet and dry bulb temperatures are known, the correction factor can be determined from Table I, Air Temperature and Relative Humidity Correction Factor for Altitude (fig 12-3), one of the tables in the lid of the altimeter. The chart is entered at the top with the wet bulb temperature and on the left side with the dry bulb temperature. The intersection of the two columns is the correction factor. *This correction factor is applied by multiplying it by the difference between the corrected scale reading of the base station altimeter and the adjusted scale reading of the field station altimeter.* The correction factor should be interpolated to the nearest thousandth in table I.

12-12. Precautions and Limitations To Be Observed When Establishing Heights by Altimetry

a. The base and field station altimeters should be observed under similar conditions in the field and protected from the sun and strong wind. The altimeter should be shaded when it is being moved between stations.

b. The altimeter must be in a horizontal position when observations are made, preferably on a level and stable surface.

c. The altimeter should be cushioned against road shock, and sudden jarring should be avoided at all times.

"B" ALTIMETER (FIELD)

DESIGNATION ALTIMETRY LEAPFROG DATE 2 AUGUST 19 67

NO WIND
WEATHER: OVERCAST CHIEF-OF-PARTY: Sgt. Brown
INSTR. NO.: # 7715 OBSERVER: Pfc. Kutchall

STATION	TIME	INST TEMP	SCALE READING	INST TEMP CORR.	CORR. SCALE READING	COMPARISON ADJUSTMENT	ADJUSTED SCALE READING	REMARKS
ARBUCKLE	1505	81	710.0	+0.5	710.5			
BNSCP-1	1530	82	702.0	+0.6	702.6	+ 1.3	703.9	
BNSCP-1	1550	82	702.5	+0.6	703.1	+ 1.1	704.2	
BNSCP-3	1650	84	691.0	+0.7	691.7	+ 0.2	691.9	
BNSCP-3	1730	87	691.0	+1.0	692.0	- 0.4	691.6	
GRUBER	1755	87	790.0	+1.0	791.0			
1	2	3	4	5	6	7	8	

Column 1 Station at Which "B" Altimeter reading is taken.
" 2 Time of observation
" 3 Instrument temperature
" 4 "B" Altimeter scale reading
" 5 Instrument temperature correction (see para. 12-9)
" 6 Corrected scale reading, algebraic sum of column 4 and 5.
" 7 Comparison adjustment. (see para. 12-10)
" 8 Adjusted scale reading, algebraic sum of column 6 and 7

Figure 12–7. Altimeter "B" recorder's notes for altimetry (modified leapfrog).

d. Observations should not be made during thunderstorms or high winds.

e. Observations should not be made at midday.

f. Intervals between comparison readings should not exceed 4 hours.

g. Watches at base and field stations must be synchronized.

h. The difference in height between the base and field station(s) should be less than 200 meters.

i. The field station(s) should be less than 20,000 meters from the base station.

Section III. PROCEDURES AND COMPUTATIONS

12–13. Leapfrog Method

a. The leapfrog method of altimetry is conducted in the manner implied by its name. Two altimeters, designated A and B, are read simultaneously at the starting base (known) station (fig 12–8). Then altimeter A is left at the base station, and altimeter B is moved to the first field station. The two altimeters are again read simultaneously, and the corrected difference in height is applied to the height of the base station to give the height of the first field station. Altimeter A is then moved from the base station, bypassing the first field station, to the second field station. Altimeter B is left at the first field station, which becomes the base station, and again simultaneous readings are made. The difference between the two altimeter readings, with appropriate corrections, is applied to the height of the first field station to determine the height of the second field station. The altimeters are then brought together at the second field

SEQUENCE OF OBSERVATIONS

DESIGNATION LEAPFROG METHOD DATE 2 AUGUST 19 67

ARBUCKLE	BNSCR-1	BNSCR-2	BNSCR-3	GRUBER	
"A"-1505	Initial Comparison Reading				
"B"-1505					
"AB"-1530	"BF"-1530				
	"BB"-1550	"AF"-1550			
		"AB"-1650	"BF"-1650		
			"BB"-1730	"AF"-1730	
	Final Comparison Reading			"A"-1755	
				"B"-1755	
A-Starting Station, Base Altimeter					
B-Starting Station, Field Altimeter					
AB-"A" Altimeter when used as base altimeter					
AF-"A" Altimeter when used as field altimeter					
BB-"B" Altimeter when used as base altimeter					
BF-"B" Altimeter when used as field altimeter					

Figure 12–8. Sequence of observations (modified leapfrog method).

station, and comparison readings are made. The station of known height, the first field station, and the second field station comprise the first leg of the altimetric survey. The same procedure is then followed from the second field station through the third field station to another comparison at the fourth field station to establish the second leg. (The term "leg" as used in altimetry, is the survey between stations where comparison readings are made with the altimeters.)

b. The advantage of the leapfrog method is that the altimeters are usually close together and operate under nearly the same atmospheric conditions. In effect, the base station is carried along with the field altimeters by the comparisons at alternate stations. The leapfrog method will determine the difference in height under normal weather conditions with an average error of ±3 meters when the difference in height between stations does not exceed 200 meters and the distance between alternate stations does not exceed 20,000 meters.

c. The leapfrog method of altimetry can be speeded up by the use of more altimeters or by a comparison of altimeter readings at every third or fourth field station instead of at alternate stations. This can be called a modified leapfrog method of altimetry. Although the latter procedure may save time and fieldwork, it may also result in reduced accuracy of the measurements because the comparisons span a greater distance and a longer period of time. This factor must be considered when selecting the leapfrog technique for an altimeter survey.

d. The field procedure for the leapfrog method of altimetry is as follows:

(1) A station of known height is used as the base station.

(2) The initial comparison reading is made at the base station with all altimeters to be used in the survey. For ease in recording and in performing subsequent computations, the initial reading and all subsequent readings should be made at even 5-minute intervals.

(3) For all readings made by the altimeter A recorder, except comparison, readings, a psychrometer reading is made and the wet and dry bulb temperatures are recorded in the field notebook opposite the scale reading. The altimeter A recorder reads and records the psychrometer readings at the time of each observation regardless of whether the altimeter A station is designated as the base or field station.

(4) The comparison adjustment is always made on the corrected scale reading of altimeter B regardless of whether the altimeter B station is designated as the base or field station.

(5) When a station is occupied by an altimeter, the altimeter is read at 5-minute intervals for a sufficient period of time to insure that simultaneous readings are being made at the base and field stations. It is important that some method of communication or signals be established before the survey is begun to insure coordination during the observations and to preclude occupation of a station longer than necessary or leaving the station too soon. Readings may be started immediately upon the arrival of the altimeter recorder at the field station unless there has been appreciable change in weather since he left the previous station. In that event, it may be necessary to wait 5 to 10 minutes until the instrument settles.

12–14. Recording Altimeter Readings

a. Altimeter and psychrometer readings are re-

COMPUTATION - ALTIMETRIC HEIGHT

(Single-Base or Leapfrog Method)
(FM 6-2)

SHEET 1 OF 1 SHEETS

LINE DESIGNATION: BASE STATION ARBUCKLE, BNSCP-1, BNSCP-2, BNSCP-3, GRUBER

	FIELD STATION NAME / TIME:	1530 BNSCP-1	1550 BNSCP-2	1650 BNSCP-3	1730 GRUBER
1	FIELD STATION DRY BULB TEMPERATURE READING (±)				
2	BASE STATION DRY BULB TEMPERATURE READING (±)	88	89	90	89
3	ALGEBRAIC SUM (1) AND (2) (±)				
4	½ OF (3) (±)				
5	FIELD STATION WET BULB TEMPERATURE READING	76	77	77	76
6	BASE STATION WET BULB TEMPERATURE READING				
7	(5) + (6)				
8	½ OF (7)				
9	FIELD STATION ADJUSTED SCALE READING	703 9	688 3	691 9	790 3
10	BASE STATION SCALE READING	712 7	704 2	687 9	691 6
11	IF (9) IS MORE THAN (10), USE (9) – (10), SIGN (+). IF (9) IS LESS THAN (10), USE (10) – (9), SIGN (–).	703 9	688 3		
		(±) 8 8	(±) 15 9	(+) 4 0	(+) 98 7
12	CORRECTION FACTOR FROM: TABLE I	1 085	1 088	1 089	1 086
	TABLE II (±)				
	TABLE III (±)				
	HEIGHT CORRECTION FACTOR (I + II + III)	1 085	1 088	1 089	1 086
13	LOG (12)	0 035 430	0 036 629	0 037 028	0 035 830
14	LOG (11)	0 944 483	1 201 397	0 602 060	1 994 317
15	(13) + (14)	0 979 913	1 238 026	0 639 088	2 030 147
16	KNOWN HEIGHT OF BASE STATION	405 1	395 6	378 3	382 7
17	NUMBER HAVING LOG (15) (Use same sign as (11))	(±) 9 5	(±) 17 3	(+) 4 4	(+) 107 2
18	ALGEBRAIC SUM (16) AND (17) = HEIGHT OF FIELD STATION	395 6	378 3	382 7	489 9

COMPUTER: WEST

CHECKER: NESMITH

DATE: 3 AUGUST 1967

DA FORM 1 OCT 63 6-27

REPLACES DA FORM 6-27, 1 SEP 54, EXISTING SUPPLIES OF WHICH WILL BE ISSUED AND USED UNTIL 1 OCT 64 UNLESS SOONER EXHAUSTED

Figure 12-9. Computations, DA Form 6-27.

GIVEN

FOR SINGLE-BASE METHOD: For each field station, altimeter scale reading at base station and adjusted scale reading at field station (taken at same time); dry bulb temperature and wet bulb temperature at base station and field station (temperature at base station interpolated to time of readings at field station); height of base station.

FOR LEAPFROG METHOD: For each leg; altimeter scale reading at base station and adjusted scale reading at first field station (taken at same time); dry bulb temperature and wet bulb temperature at base station and first field station (taken at same time); height of base station. Adjusted scale reading at first field station (base station for second half of leg) and altimeter scale reading at second field station (taken at same time); dry bulb temperature and wet bulb temperature at first and second field stations (taken at same time).

GUIDE

FOR LEAPFROG METHOD: Height of base station for each field station except the first field station is height computed for previous field station.

FOR BOTH METHODS: Use known heights to nearest one-tenth meter. Convert known height to meters when given in feet or yards.

Use logarithms to five places.

When known height of base station in step (16) is below sea level, use step (16) as a negative value and proceed with computation.

Refer to TM 6-200 for additional information.

RESULTS

FOR SINGLE-BASE METHOD: It can be expected that heights determined will have a maximum error of 4 meters and an average error of 1 1/2 meter when observations using standard equipment are made as prescribed.

FOR LEAPFROG METHOD: It can be expected that heights determined will have a maximum error of 2 meters and an average error of 1/2 meter when observations using standard equipment are made as prescribed.

FORMULA

$D = C(B - A) + E$

A = base station adjusted scale reading
B = field station adjusted scale reading
C = height correction factor
D = height of field station
E = known height of base station

HEIGHT CONVERSION - BASE STATION

FEET TO METERS		BASE STATION	YARDS TO METERS		BASE STATION
1	HEIGHT IN FEET	1 329 1	1	HEIGHT IN YARDS	
2	LOG OF HEIGHT	3 123 56	2	LOG OF HEIGHT	
3	LOG CONVERSION FACTOR	9 4 8 4 0 2	3	LOG CONVERSION FACTOR	9 9 6 1 1 4
4	(2) + (3)	2 607 58	4	(2) + (3)	
5	NUMBER HAVING LOG (4) = HEIGHT IN METERS	405 1	5	NUMBER HAVING LOG (4) = HEIGHT IN METERS	

Figure 12-10. Reverse, DA Form 6-27.

corded in the field notebook that accompanies each altimeter used in the survey. For the leapfrog method, the following data are recorded in the notebook of altimeter A (fig 12–6):

(1) Station at which observation is made.
(2) Time of observation.
(3) Instrument temperature.
(4) Scale readings.
(5) Instrument temperature correction.
(6) Corrected scale readings.
(7) Wet and dry bulb temperatures.

Note. Items 2, 3, 4, and 7 above are field data determined by reading the scales at each station. Items 5 and 6 are values determined as a result of these field readings.

b. The following data are recorded in the field notebook of altimeter B (fig 12–7):

(1) Station at which observation is made.
(2) Time of observation.
(3) Instrument temperature.
(4) Scale readings.
(5) Instrument temperature correction.
(6) Corrected scale readings.
(7) Comparison adjustment.
(8) Adjusted scale readings.

Note. Items 2, 3, and 4 above are field data determined by reading the scales at each station. Items 5, 6, 7, and 8 are values determined as a result of these field readings. The comparison adjustment (item 7) is extracted from the comparison adjustment graph that is constructed for each leg in the field notebook.

12–15. Computations

a. Heights of stations are computed on DA Form 6–27 (Computations—Altimetric Height) (fig 12–9). Each column of the form is designed to be used to determine the height of one field station. As an aid in extracting the correct data from the field notebooks for entry on the form, the time of observation should be entered in the FIELD STATION NAME block. The wet and dry bulb temperatures and the corrected scale reading from the field notebook of altimeter A and the adjusted scale reading from the field notebook of altimeter B are extracted and entered in the approprate blocks on the form. The air temperature and relative humidity correction factor is extracted from table I and applied to the difference in scale readings by using six-place logarithms (use available tables and round off if necessary). The known height of the base station (block 16) is the height of the starting station in meters. The reverse of the form (fig 12–10) contains a block for height conversion, if height conversion is necessary.

b. In the leapfrog method, the height determined for the first field station (block 18) becomes the known height of the second base station (block 16) and so forth for each successive station throughout the scheme. An example of the sequence of observations, leapfrog method, is shown in figure 12–8.

12–16. Single-Base Method

The field procedure for the single-base method of altimetry is identical with that of the leapfrog method with the following exceptions:

a. In the single-base method, after the initial comparison readings are made at the base station, the altimeter A recorder remains in position at the base station and makes readings at 5-minute intervals throughout the observing period. After the initial comparison, the altimeter B recorder visits the field stations in sequence and makes simultaneous readings. After the readings have been made at the last field station, altimeter B is returned to the base station and a final comparison is made. For economy of time and effort more than one field altimeter can be used in conjunction with the base altimeter with no reduction in accuracy.

b. The computation of heights of stations on DA Form 6–27 for the single base method is the same as that for the leapfrog method except for one difference. In the single-base method, the known height of the base station (block 16) remains the same for the computation of heights of all field stations, since the base station remains fixed throughout the observing period.

CHAPTER 13

SURVEY COMPUATIONS WITH GUN DIRECTION COMPUTER M18 (FADAC)

Section I. OPERATION OF FADAC AND AUXILIARY EQUIPMENT

13–1. General

Survey program tapes for the gun direction computer M18 (FADAC) have been developed by the U.S. Army Field Artillery School for interim use pending procurement of production model tapes. One FADAC (fig 13–1) is authorized for issue to each division artillery target acquisition battalion survey information center. One teletypewriter TT–537G and one signal data reproducer AN/GSQ–64 are authorized for each FADAC issued. The U.S. Army Field Artillery School program tapes are used to check field computations and to perform the computations required of the survey information centers (SIC). Certain minor differences in computational results between the FADAC and manual methods will appear due to the formulas and round-off procedures that are used. Computational limitations are covered in the explanation of each program.

Note. The TT AN/TGC–14A was previously issued for use with FADAC and will be discussed in this chapter, however, the TT 537–G (FSN 5815–926–7378, SB 700–20, app A) is currently authorized for issue with FADAC in lieu of TT AN/TGC–14A. Operational data for the TT–537G is issued with this teletypewriter.

13–2. Operating Controls of FADAC

The functions of the operating controls and indicators of the FADAC (fig 13–2) are discussed in *a* through *g* below.

a. Power Control Panel. The functions of the power panel controls (fig 13–3) are as follows:

(1) *POWER ON-OFF switch.* When the POWER switch is momentarily moved to the ON position, the power control circuits are activated, energizing (in the proper sequence) the power supply, blowers, and memory. When the POWER switch is momentarily moved to the OFF position, the computer is deenergized.

(2) *POWER READY indicator.* The POWER READY indicator lights approximately 20 seconds after the POWER switch is turned on, indicating that the computer is ready for use. The indicator remains on until the POWER switch is turned off. The indicator blinks when the computer is in the marginal test mode.

(3) *Time meter.* The time meter records the total operational hours accumulated by the computer.

(4) *LIGHTS ON-OFF switch.* The LIGHTS ON-OFF switch, when turned ON, lights two hooded illuminating lamps for night operations.

b. Indicator Display. The indicator display is a programmed visual display in which input or recalled data are displayed. The display consists of 17 Nixie lights used for the display of numerals and 16 neon lights used for the display of decimals. In the survey programs, each key symbol depressed is displayed, shifting from right to left as subsequent keys are depressed. (Plus or minus signs are displayed at the "sign" Nixie.)

c. Trouble Indicator Panel. The functions of the trouble indicator panel controls (fig 13–4) are discussed in (1) through (7) below.

(1) *TEMP indicator.* The TEMP indicator, which normally is on, blinks when normal operating temperatures are exceeded. Should this occur, the air filters should be cleaned or replaced.

(2) *TRANSIENT indicator.* The TRANSIENT indicator, which is normally on, blinks when there is a line voltage transient or when the voltages exceed high or low tolerances.

(3) *PARITY indicator.* The PARITY indicator, which is normally on, blinks when incorrect information is transferred from an input device to memory or from memory to an output.

(4) *ERROR indicator.* The ERROR indicator, which is normally on, blinks when there is an internal overflow or an error verification. Depressing the RESET button will cause the blinking to cease. Input data should then be checked.

(5) *SET UP button.* The SET UP button is a momentary-push switch used to clear the memory

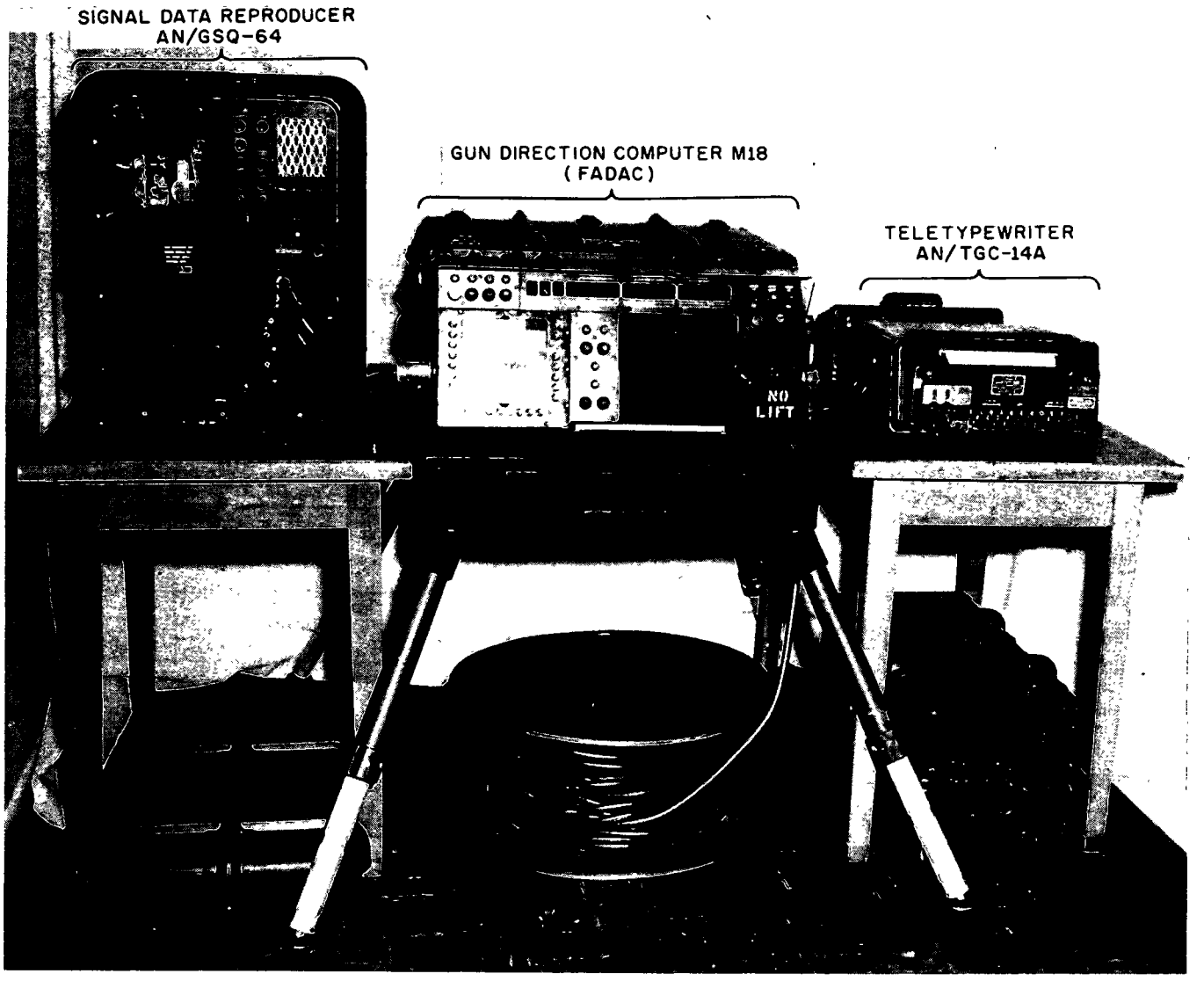


Figure 13–1. FADAC and auxiliary equipment.

of previously stored data for a particular program. It also stores a code word in key memory locations, which will allow the program to activate the NO SOLUTION indicator if the operator attempts to compute without entering all the required data.

(6) *PROG TEST button.* The PROG TEST button is not used in survey programs.

(7) *RESET button.* The RESET button is used when an error has occurred; the error causes the ERROR indicator or the PARITY indicator to blink. Depressing this button clears the trouble indicator, and the operator must repeat the previous step(s). The RESET button is also used to terminate the input or compute mode, leaving the computer in the halt mode.

d. Input Selection Matrix. The input selection matrix (fig 13–5) consists of 64 indicating windows arranged in an 8 by 8 array. The buttons used to select a specific input window, corresponding to an input parameter, are of the latching type. They are located in the left-hand column (lettered A through H) and in the bottom row (numbered 1 through 8). In addition to the 8 by 8 matrix, there are several auxiliary buttons as described in (1) and (2) below.

(1) Buttons lettered A, B, C, D, and E on the right-hand bank are used to select portions of a problem for solution.

(2) Buttons numbered 1 and 2 on the right-hand bank are used to select further portions of a problem for solution.

e. Operator Panel. The functions of the operator panel controls (fig 13–6) are discussed in (1) through (8) below.

(1) *NO SOLUTION indicator.* The NO SOLUTION indicator, which is normally on, blinks when data entered cause computational results to exceed the limitations of a particular program. Depressing the RECEIVE button will cause the blinking to cease. Input data should then be checked.

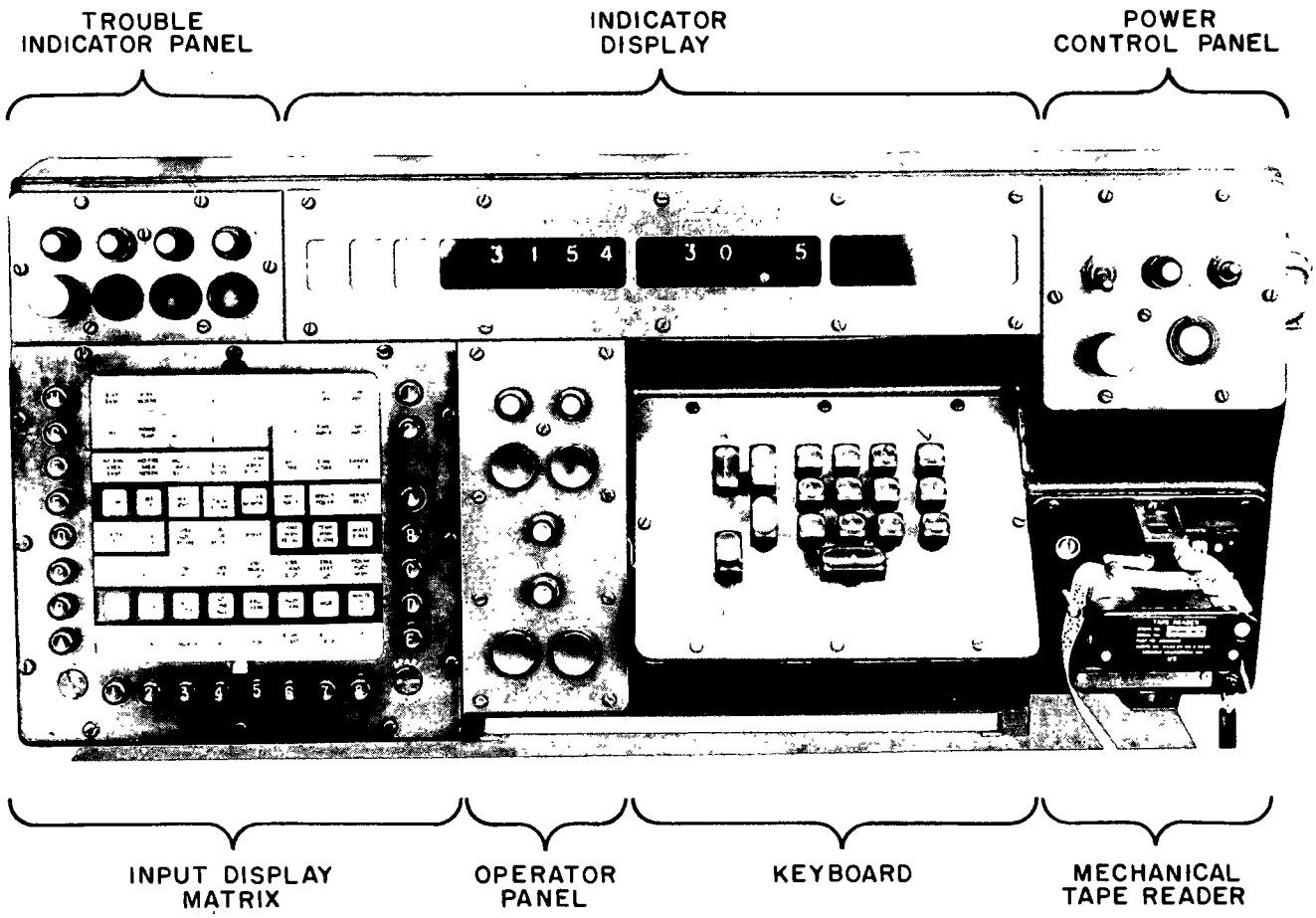


Figure 13–2. FADAC main control panel—front view.

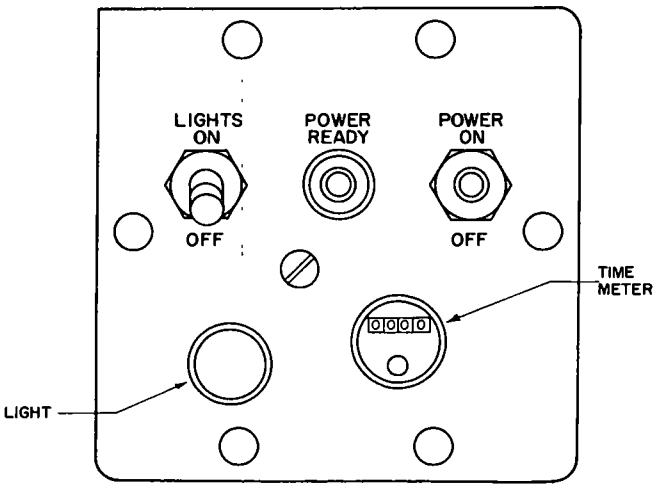


Figure 13–3. Power control panel.

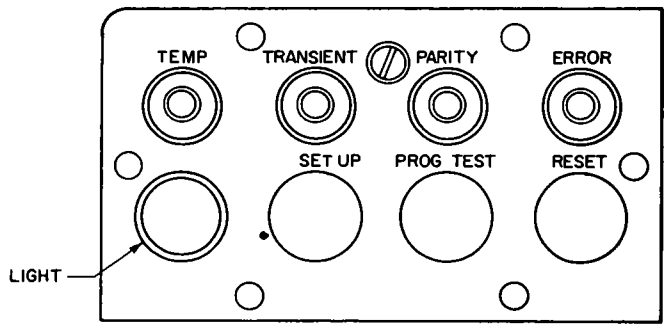


Figure 13–4. Trouble indicator panel.

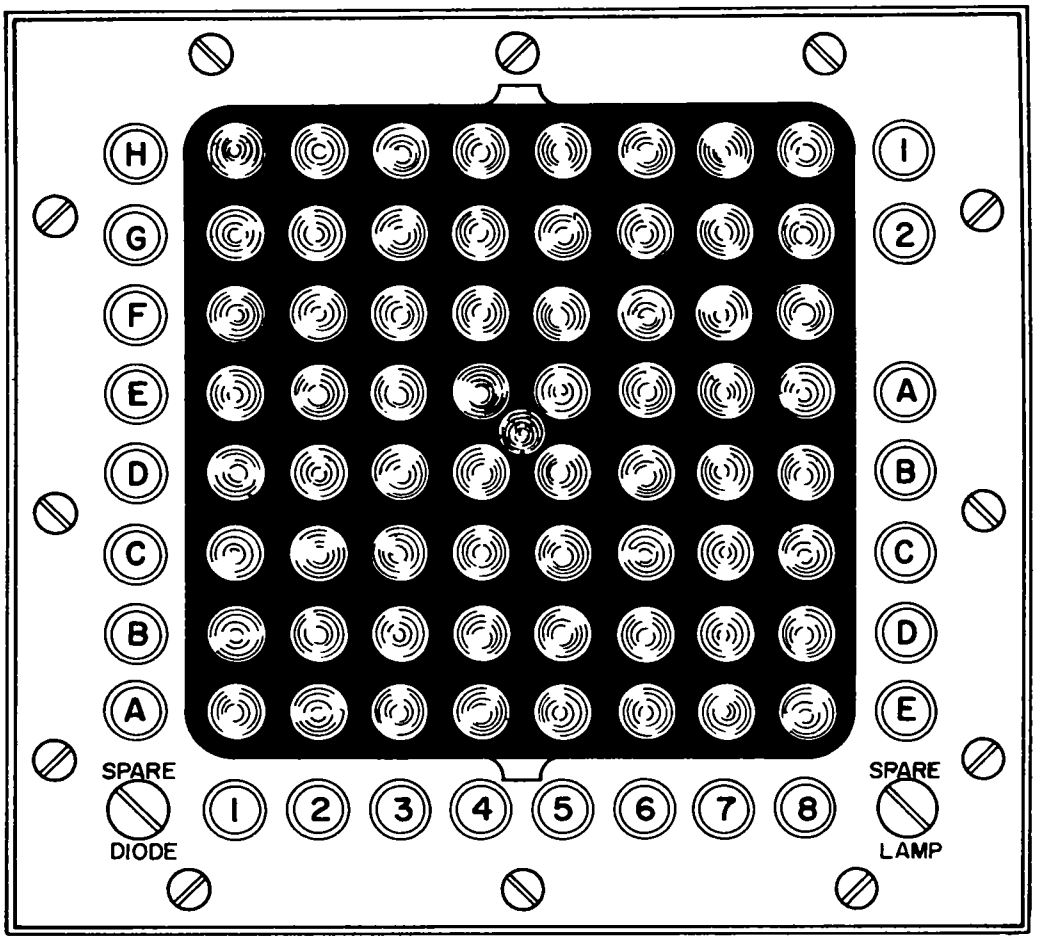


Figure 13–5. Input selection matrix.

(2) *COMPUTE indicator.* The COMPUTE indicator, which is normally off, lights during the periods when the computer is in the compute mode.

(3) *KEYBOARD indicator.* The KEYBOARD indicator, which is normally off, lights when the computer calls for information from the keyboard.

(4) *IN OUT indicator.* The IN OUT indicator, which is normally off, lights when information is being transferred to or from any input-output device.

(5) *TRIG button.* The TRIG button when momentarily depressed allows the computation of certain trigonometric problems otherwise beyond program limitations.

(6) *COMPUTE button.* The COMPUTE button when momentarily depressed sets the computer into the compute mode. (The keyboard must not be activated.)

(7) *SEND button.* The SEND button is used to command typeout of values indicated on the Indicator Display.

(8) *RECEIVE button.* The RECEIVE button is used to turn off the NO SOLUTION indicator and to turn on the printer output circuit.

f. Keyboard. The computer keyboard (fig 13–7) is used for manual input of information. It contains keys for the digits 0 through 9, one key each for + and —, decimal (.), and four control keys (CLEAR, ENTER, RECALL, and SM (sample matrix)). The functions of the keyboard keys are discussed in (1) through (7) below.

(1) *DECIMAL key (.).* The DECIMAL key is used to indicate a decimal or a period to separate degrees, minutes, and seconds when sexagesimal angles are entered.

(2) *PLUS key (+).* The PLUS key is used, if desired (but not necessary) to enter positive values.

(3) *MINUS key (—).* The MINUS key is used to indicate negative numbers or angles. It may be depressed at any time prior to entering data.

(4) *CLEAR key.* The CLEAR key is used to

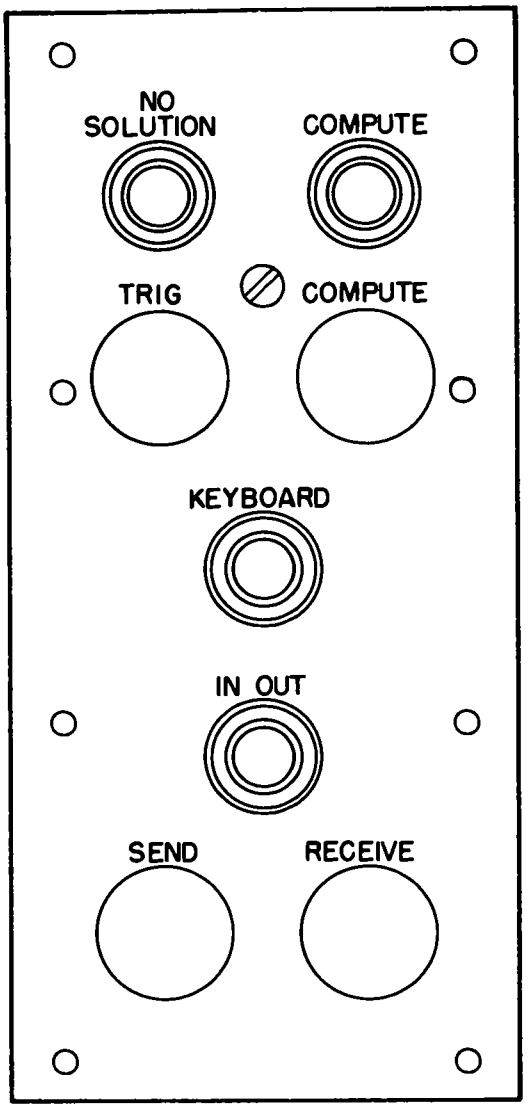


Figure 13–6. Operator panel.

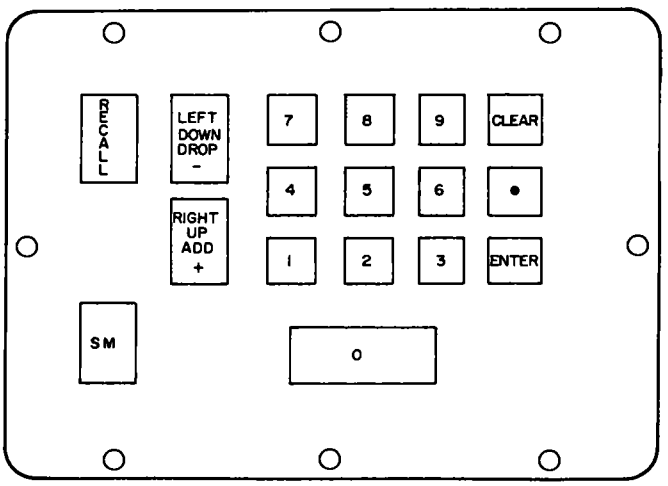


Figure 13–7. Keyboard.

clear the keyboard and Indicator Display of any erroneous data prior to entry.

(5) *ENTER key.* The ENTER key is used to enter data into the computer memory.

(6) *RECALL key.* The RECALL key is used to recall data previously entered at a given matrix position. The leg or figure number must be entered prior to designating a matrix position for recall.

(7) *SM key.* The SM key is used to energize the keyboard and allow data for a particular matrix position to be entered. It is also used to select each of the programs. Matrix positions cannot be changed while the keyboard is energized.

g. Mechanical Tape Reader. The mechanical tape reader is used for entering short paper tape data, such as met messages, into memory and to read a clear memory tape.

13–3. Operation of Signal Data Reproducer AN/GSQ–64

The signal data reproducer (SDR) (TM 9–1290–326–12) is a high-speed, photoelectric paper tape reader which operates at 670 characters per second. The purpose of the signal data reproducer is to fill a given computer program into memory. The following are the functions of the controls of the signal data reproducer:

a. POWER ON/OFF Switch (Toggle). Applies primary power to the drive motor and the blower.

b. SIGNAL ON/OFF Switch (Toggle). Applies primary power to the DF power supplies.

c. FILL Switch (Pushbutton). Starts tape running past the photo reader to fill the computer memory. This can only be accomplished when the COMPUTE switch is in the HALT position.

d. FILL Indicator. Lights when the computer is in the FILL mode.

e. VERIFY Indicator. Lights when the computer is in the VERIFY mode.

f. STOP Switch (Pushbutton). Unconditionally stops in the reader. This is used when the tape reader is not properly feeding the tape past the read head.

g. TAPE SELECTOR Switch (Two-Way Toggle). Optionally selects the input tape code to be used: a five-level tape for teletype; or an eight-level tape for field data. The survey programs use the *five-level teletype code.*

h. COMPUTE Switch (Two-Way Toggle). Immediately starts computing when placed in the RUN position, beginning with the instruction cur-

rently in the instruction register. In the HALT position, the computer stops the computation after completing any instruction that was being executed in the instruction register. The computer then enters the manual HALT state. After the execution of a HALT instruction under program control, the operation of the COMPUTE switch from RUN to HALT and back to RUN will begin a computation in the location specified by the next instruction address portion of the HALT instruction.

i. TAPE ADVANCE Switch (Two-Way Toggle). Starts the tape reader when switched from the normal position of OFF to On. Information signals are inhibited from passing into the computer; the reader runs until it reaches a space of 10 or more sprocket holes or until the switch is released.

13–4. FADAC and Signal Data Reproducer Procedures

The procedures for setting up the FADAC and signal data reproducer are discussed in *a* through *l* below.

a. Set up the FADAC field table.

b. Place the FADAC on the field table and open the pressure release valve; then remove front and rear covers.

c. Connect the power cable from the proper power source to junction J5 on the field table. (The FADAC requires a 400-cycle, 3-phase, 4-wire 120/208 volt power source.)

d. Turn the CIRCUIT BREAKER to OFF and connect power cable P11 from the field table to the J11 connection on the FADAC, turn CIRCUIT BREAKER to ON position.

e. Check to insure that the air intake located below the keyboard is free from obstruction.

f. Insure that the MEMORY SELECTION switch is in the 4 position to prevent altering cold memory storage. (Organizational maintenance only.)

g. Place the signal data reproducer on a table to the left of the FADAC.

h. Connect the power cable from the field table to junction PA on the signal data reproducer.

i. Connect the photo-reading cable to junction J17 on the FADAC and to junction PB on the signal data reproducer.

j. Activate the POWER ON and SIGNAL ON switches on the signal data reproducer. The COMPUTE-RUN switch and the AUXILIARY MEMORY switch must be in the HALT (off) position. The TAPE ADVANCE switch must be off. The FILL-VERIFY switch must be in the VERIFY position. The CODE switch must be in the TELETYPE position.

k. Turn on the POWER ON switch of the FADAC.

l. When the FADAC POWER READY indicator comes on, the computer is ready for memory loading.

13–5. Loading Survey Tapes Into Memory

a. Two separate survey program tapes with different survey methods are available. The nomenclature is as follows: kit, tape, prepunched field artillery survey program for: computer, gun direction, M18 (FADAC), part number 8213315–36/37, Rev A, FSN 1220–999–6303. These program tapes are referred to as tape 1 and tape 2, and are to be used when TT AN/TGC–14A is used. Depending on the survey method to be computed, one or the other survey program tape is loaded into the memory of the FADAC. Each program tape contains two sets of the punched program information separated by a halt and a verify code. Survey tapes 1 and 2 have both been revised (referred to as Revision A) for use with the TT–537G (now available for issue with FADAC in lieu of TT AN/TGC–14A).

b. To load a survey tape into the memory of the FADAC, place the program tape in the canister so that the wider side faces inward toward the signal data reproducer. Thread the tape over the spindles and through the reader. Check for proper seating of the tape in the reader tracks. Depress the START button on the signal data reproducer. The FILL indicator will come on. The reader should read the tape into memory and halt at the end of the first copy of the program tape. This step must be repeated if the tape halts for any reason before reading the halt code.

c. To verify that the tape has been properly loaded into the memory, depress the FILL button on the signal data reproducer. This will cause the tape to advance, pass a verify code, and read the second copy of the program. When the *verify code* passes the reader, the VERIFY indicator will come on. If an error is detected, the reader will halt, and the ERROR indicator will blink. In this case, depress the RESET button to turn off the

ERROR indicator and repeat *b* above. When the tape stops running through the reader, check to make sure that the *halt code* has passed the reader.

Note. Program tapes are made of paper-punched tape with 8½-inch folds. The tape is eleven-sixteenths of an inch wide, with a line of guide holes running the length of the tape and slightly off center (fig 13–8 and 13–9).

13–6. Preparation of Teletypewriter AN/TGC–14A for Operation

Note. See the technical manual furnished with each teletypewriter.

To prepare the teletypewriter AN/TGC–14A for operation:

a. Remove the upper case by using the carrying handle.

b. Remove the front cover of the typewriter.

c. Slide the typewriter forward out of the lower case.

d. Check the timing gear (should be the small, orange gear).

e. Slide the typewriter back into the lower case and replace the front cover.

f. Remove the two air vent covers.

g. Remove the cable from the top of the carrying case and connect it to the FADAC power table and the teletypewriter. If the teletypewriter does not have a fitting for the J010 connection on the FADAC, two lengths of field wire 3 to 4 feet long will serve the purpose. Connect these to two paper clips inserted into the FADAC J010 plug at the locations "X" and "Y". Connect the other two ends to the two receive-line binding posts on the power cable assembly. The two send-line binding posts should be wired together with a short length of field wire. Connect the ground connection to the FADAC power table.

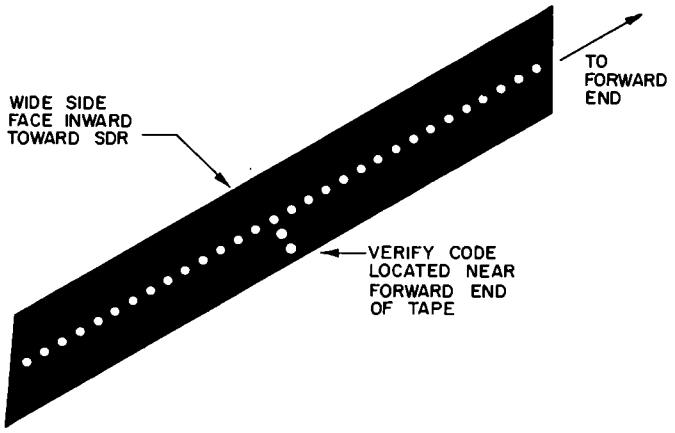


Figure 13–8. Program tape (front).

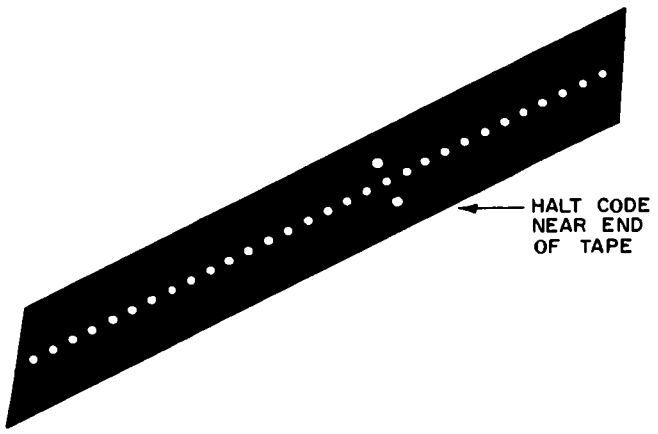


Figure 13–9. Program tape (end).

h. It is not necessary to place the keyboard in the operating position.

13–7. Preparation for Computations

a. After the program tape has been read into the memory, turn off the FADAC. (The signal data reproducer should then be turned off and disconnected from the FADAC at the J017 connection.)

b. Always wait at least 1 minute before turning on the FADAC after it has been turned off.

c. Turn on the FADAC and wait for the POWER READY indicator to remain on.

d. Depress the RECEIVE button on the FADAC and turn on the teletypewriter.

Section II. SURVEY PROGRAM TAPE NUMBER 1

13–8. Survey Computations

a. Tape 1 Programs. Survey program tape number 1 contains the following programs:

(1) Program test.

(2) Traverse.

(3) Traverse adjustment.

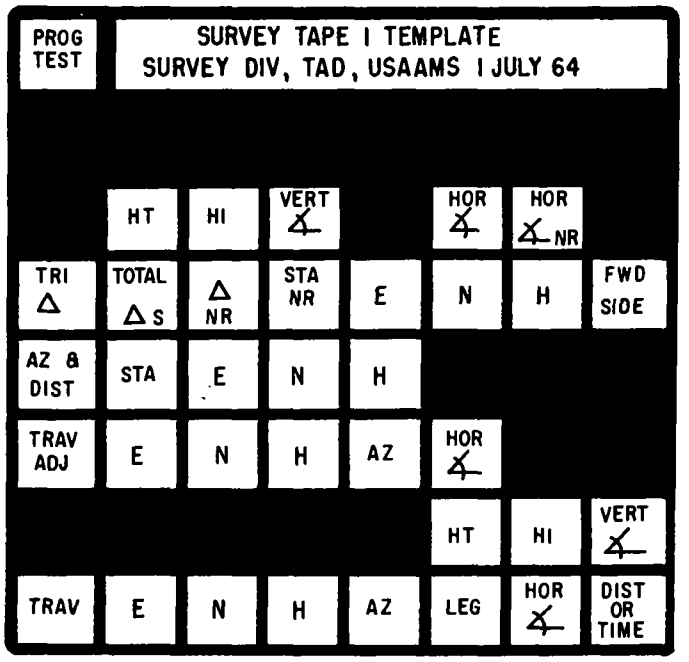


Figure 13–10. Matrix template—survey program tape number 1.

(4) Azimuth and distance from coordinates.

(5) Triangulation.

b. Matrix Template. The matrix template used with survey program tape number 1 is shown in figure 13–10.

13–9. Program Test

The test program is selected by depressing matrix buttons H–1. This program adds all the binary bits of information in the instruction channels and compares this sum with a predetermined check sum. When these sums agree, the program causes a printout of "SATISFACTORY". If erroneous data are contained in any memory location, the check sums will not agree and the program will cause a printout of "UNSATISFACTORY" or a blinking ERROR indicator. In either event, the program tape must be reloaded into the FADAC memory. The program test is initiated by depressing the COMPUTE button. The program test should be performed daily with the MARGINAL TEST switch in each of the five test positions. The POWER READY indicator will blink when the computer is in the marginal test mode. If the program test fails in any of the test positions, the radio mechanic should be notified to perform further checkout of the computer by using the FADAC automatic logic tester (FALT).

13–10. Traverse

a. Depressing matrix buttons A–1 will cause the light to come on in the A–1 position which is indicated on the template as "TRAV". When this light is on, depressing the SM key signals the computer that the traverse program is desired. The teletypewriter will type out "TRAVERSE". Then the SET UP button is depressed to clear the memory of any traverse data previously entered, and causes the same typeout. The computer is now prepared to receive data for 1 to 10 traverse legs.

b. If angles are to be entered in mils, the 1 button must be depressed; if in degrees, the 2 button must be depressed. Once an angle has been entered in either unit, it may be recalled in terms of the other by changing the button settings. (See recall procedure in *e* below.)

c. When entering vertical angles enter only the vertical angle from the occupied to the forward station. The traverse program of the FADAC automatically applies corrections for earth curvature and refraction to all traverse computations thereby eliminating the need for reciprocal vertical angles. *Never enter reciprocal vertical angles as raw data in FADAC traverse computations.*

d. Button A is depressed if distances are to be entered as horizontal (taped, in meters); button B, for tellurometer transit time; and button C, for slope distances in meters. Buttons D and E are not used in the survey programs.

e. Data for the traverse should be entered as shown in the example below. After each item is selected, the *SM key must be depressed* to light up the KEYBOARD indicator and energize the keyboard. Data entered will appear on the Nixie display for verification by the operator. After the desired data are entered on the keyboard and the Nixie display is verified, the ENTER key must be depressed to enter the data into the computer memory. As each item is entered, it is automatically typed out. Data are entered as shown in the following example:

Matrix position	Input	Example	Remarks
A-2	EASTING of starting station	550242.64	(2 decimal places)
A-3	NORTHING of starting station	3835402.33	(2 decimal places)
A-4	HEIGHT of starting station	642.26	(1 or 2 decimal places)
A-5	Azimuth to mark Degrees	94° .03′ .45″	(Separate with decimals)
	Mils	1672.224	(3 decimal places)
A-6	LEG NUMBER	1	(Digits 1 to 10)
A-7	HORIZONTAL ANGLES Degrees	136° .20′ .24″	(Separate with decimals)
	Mils	2426.488	(3 decimal places)
A-8	DISTANCE		(Select button A, B, or C)
Matrix button A	Horizontal taped distance in meters	765.43	(2 decimal places)
Matrix button B	Tellurometer transit time (millimicroseconds)	5106.42	(2 decimal places)
Matrix button C	Slope distance in meters	765.43	(2 decimal places)
B-8	VERTICAL ANGLE Degrees	−00° .10′ .08″	(Separate with decimals)
	Mils	−3.002	(3 decimal places)
B-7	HEIGHT OF INSTRUMENT (HI) (if desired)	1.6 (meters)	(1 or 2 decimal places)
B-6	HEIGHT OF TARGET (HT) (if desired)	1.6 (meters)	(1 or 2 decimal places)

Printout of solution:

550242.64		3835402.33		642.26		1672.224	
01	2426.488		765.43		−3.002	1.60	1.60
549651.86		3834916.24		640.04		4089.712	898.712

Note. Vertical angles are assumed to be positive unless the *minus* sign is entered. A plus sign may be entered if desired but is unnecessary. The sign may be entered at any time before depressing the ENTER key. Entry of an unrealistic vertical angle will cause a NO SOLUTION error and the program will type out "HEIGHT NG". Both HI and HT may be omitted, but, if either is entered, then the other must also be entered. Leg 1(A-6) must be reentered prior to depressing the COMPUTE button, signaling the computer the location at which computations are to begin. The starting data will be typed out, followed by the data entered for leg 1; the E, N, and H of TS-1; the forward azimuth and back-azimuth; and so on for each leg entered, up to 10. When the last leg has been computed, the NO SOLUTION indicator will flicker. It may be inactivated by depressing the RECEIVE button. When working in mils, an occasional azimuth error of 0.001 mil will appear due to round-off and conversion procedures. This does not materially affect the accuracy of the computations.

f. When traverse legs greater than 3,000 meters are used, the azimuth computed by FADAC will often differ more than 0.001 mil from that computed manually. The longer the distance between stations, the greater this difference will be. Also of significance is the fact that the back azimuth will not differ exactly 3200 mils from the forward azimuth. These differences are caused by the application of a special correction (projected geodetic azimuth versus plane azimuth) within the FADAC program. Therefore, the azimuth carried by FADAC is more accurate than the azimuth carried by manual methods.

g. Coordinates computed by FADAC will begin to differ noticeably from coordinates computed manually when traverse legs are 10,000 meters or longer. This is caused by the application of the special corrections described in *f* above and application of the log scale factor throughout the length of the traverse leg rather than only at the beginning of the traverse leg as is normally done manually. Again, the answers computed by the FADAC are more accurate than those resulting from manual computations because these various corrections are automatically applied in all traverse computations.

h. There will be many occasions when verification or recall of previous input data is desired. To recall input data, select and enter the leg number (A-6), (the desired matrix position will light), and depress the RECALL key. The SM key is *not* used in the recall procedure after the desired leg (or figure) number is entered. If this should occur, depress the RESET button and the RECALL key will then recall the data.

Caution: **When traversing across the Equator in a southerly direction, the operator must exercise caution because the computation will not compensate for the change in the northing coordinate system.**

13–11. TRAVERSE ADJUSTMENT

a. Matrix position C–1 selects this program. Depressing the SM key will cause the program to type out "TRAVERSE ADJUSTMENT". Then the SET UP button is depressed to clear the memory of any data previously entered, and causes the same typeout. (After a traverse has been computed and typed out, the computational results are retained in the computer memory.) In this program, the correct closing coordinates are entered along with the correct closing azimuth, the last horizontal angle turned (to the azimuth mark at the closing station), and the correct closing height. Data are entered as shown in the following example:

Matrix position	Input		Example	Remarks
C–2	Correct EASTING of closing station		549652.02	(2 decimal places)
C–3	Correct NORTHING of closing station		3834916.44	(2 decimal places)
C–4	Correct HEIGHT of closing station		640.20	(1 or 2 decimal places)
C–5	Correct closing AZIMUTH	Degrees	330° .11′ .15″	(Separate with decimals)
		Mils	5870.002	(3 decimal places)
C–6	Last horizontal angle turned	Degrees	279° .37′ .59″	(Separate with decimals)
		Mils	4971.256	(3 decimal places)

Printout of input:

549652.02	3834916.44	640.20	5870.002	4971.256

Printout of trig solution:

.16	.20	.16	.034	

Printout of solution:

550242.64		3835402.33	642.26	1672.224	
01	2426.505	765.43	−3.002	.00	.00
549652.02		3834916.44	640.20	4098.729	898.729

b. Depressing the TRIG button (if desired) will cause the computer to print out the closure differences. This should be done prior to computing. When the COMPUTE button is depressed, the computation will proceed. The traverse is recomputed and typed out again with corrected coordinates and azimuth. Once the COMPUTE button has been depressed, the original traverse data is destroyed.

c. The combined traverse and traverse adjustment programs also provide the capability for conversion to common control, known also as swinging and sliding the grid. This requires that the correct starting coordinates and azimuth be entered in the traverse program; it requires recomputing the traverse and adjusting, if necessary, with the traverse adjustment program.

d. The data which were entered for each leg will be typed out, followed by the correct easting, northing, height, forward azimuth, and back-azimuth.

e. When the computation reaches the end of leg 10 (or any leg for which all data has not been entered), the NO SOLUTION indicator will flicker. When this happens, depressing the RECEIVE button will cause the indicator to remain on.

13–12. AZIMUTH AND DISTANCE FROM COORDINATES

a. Matrix position D–1 selects this program. Depressing the SM key will cause the program to type out "AZIMUTH AND DISTANCE FROM COORDINATES". Then the SET UP button is depressed to clear the memory of any previous AZIMUTH and DISTANCE data, causing the same typeout. Data are entered as shown in the following example:

Matrix position	Input	Example	Remarks
D–2	STATION	3	(Enter zero for station of origin or a number from 1 to 10 for the number of the station)
D–3	EASTING	550431.32	(2 decimal places)
D–4	NORTHING	3835641.36	(2 decimal places)
D–5	HEIGHT	302.14	(1 or 2 decimal places)

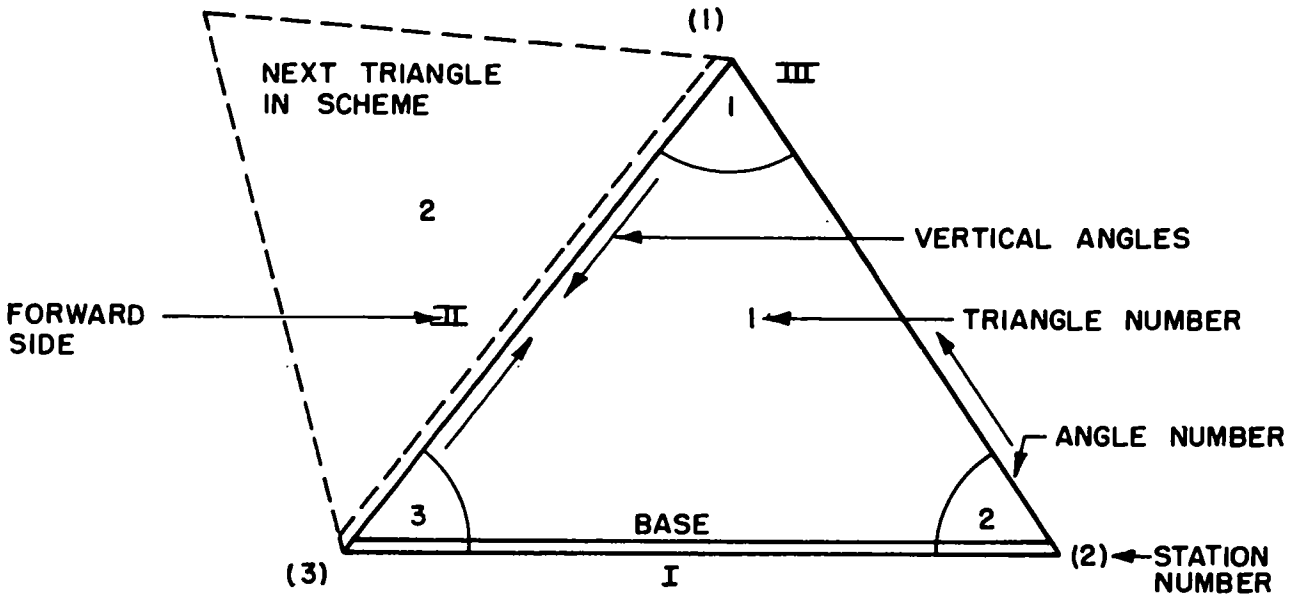


Figure 13–11. Triangulation.

b. Matrix position D–2 selects the station number. The station of origin is designated as zero. The easting, northing, and height of this station are then entered.

c. One to ten stations may be entered, each with its easting, northing, and height in sequence.

d. The COMPUTE button is depressed and computation begins. The following example shows the printout format:

Printout of Solution (mils):

00	560471.47	3847039.01	407.50
01	564493.79	3846440.39	393.50
1750.487	4066.62	—	3.507
(Azimuth)	(Distance)*		(Vertical angle)**

*This is the UTM grid distance, which should not be confused with the distance obtained by *taping*.

**This is the *computed* vertical angle, which should not be confused with the vertical angle obtained by field *measurement*.

13–13. TRIANGULATION

a. Matrix position E–1 selects this program. Depressing the SM key causes the program to type out "TRIANGULATION". The SET UP button is then always depressed to clear the memory of any previously entered triangulation data, causing the same typeout.

b. This program computes one to twelve triangles at a time. Prior to entering data, each triangle should be sketeched and labeled as shown in figure 13–11.

c. The angles and stations for each triangle are numbered from 1 to 3 in a clockwise manner, always starting at the apex.

d. For the first triangle, the E, N, and H must be entered for stations 2 and 3 after all angles for all triangles have been entered.

e. All the angles for triangle number 1 must be entered prior to entering the angles for triangle number 2.

f. The vertical angles are required from station 2 and station 3 to station 1 and from station 1 to station 2 or station 3, whichever happens to lie on the selected forward side.

g. The forward sides, matrix position E–8 should be entered after the coordinates and heights of station 2 and 3 have been entered for triangle number 1.

h. Prior to computing, triangle number 1 (E–3) should be entered. Input data are as shown in the example below:

Matrix position	Input		Example	Remarks
E-2	TOTAL NO OF TRIANGLES		3 (1-12)	
E-3	TRIANGLE NO		1 (1-12)	
E-4	STATION NO		2 (2 and 3 for first triangle only)	
E-5	EASTING		553641.79	(2 decimal points)
E-6	NORTHING		3838746.23	(2 decimal places)
E-7	HEIGHT		321.62	(1-2 decimal places)
E-8	FORWARD SIDE		2	(side II or III)
F-7	HORIZONTAL ANGLE NO		1	(1-3 for each triangle)
F-6	HORIZONTAL ANGLE	Degrees	52° .27′ .40″	(Separate with periods)
		Mils	932.643	(1-3 decimal places)
F-4	VERTICAL ANGLE	Degrees	−00° .17′ .33″	(Separate with periods)
		Mils	−5.200	(1-3 decimal places)
F-3	HEIGHT OF INSTRUMENT		1.6	(Operational; if either is entered, then the other must be entered also)
F-2	HEIGHT OF TARGET		1.6	

Printout of solution:

```
01
02    553641.79          3838746.23   321.62
03    555624.78          3837987.53   386.54
 3         2    856.742          3  1410.615          1    932.643
1.60      1.60    1.60        1.60  01       554579.28  3836287.45   346.46
```

i. When the COMPUTE button is depressed, the data entered will be printed, followed by the coordinates and height of station 1.

Section III. SURVEY TAPE PROGRAM TAPE NUMBER 2

13-14. Survey Computations

a. Clarke 1866 Spheroid. Survey program tape number 2 is programmed to compute only for the Clarke 1866 spheroid in the Southern Hemisphere. Input data must be converted to the Northern Hemisphere coordinate system prior to initiating computations for other spheroids in the Southern Hemisphere.

b. Tape 2 Programs. Survey program tape number 2 has the following programs:

(1) Program test.

(2) UTM to geographic coordinates.

(3) Zone-to-zone transformation of coordinates and azimuth.

(4) Azimuth by hour-angle method.

(5) Azimuth by altitude method.

(6) Geographic to UTM coordinates.

(7) Grid convergence.

c. Matrix Template. The matrix template for survey tape number 2 is shown in figure 13-12.

13-15. Program Test

Matrix position C-8 selects this program. It functions the same as on survey program tape number 1.

13-16. UTM TO GEOGRAPHIC

a. Matrix position H-1 sleects this program. Depressing the SM key causes the program to type out "UTM TO GEOGRAPHIC". The SET UP button is then depressed to erase any data previously entered, causing the same typeout.

b. Input data are as shown in the following example:

Matrix position	Input	Example	Remarks
H-2	HEMISPHERE REFERENCE	±1	North (±1)
H-3	SPHEROID	(1-5)	1. CLARKE 1866 2. INTERNATIONAL 3. CLARKE 1880 4. EVEREST 5. BESSEL
H-4	UTM GRID ZONE NO	14	(1-60 zones)
H-5	EASTING	524346.27	(2 decimal places)
H-6	NORTHING	3835432.73	(2 decimal places)

Printout of Input:

1.	1.	14.	524346.27	3835432.73	

Printout of Solution:

34	39	44.364	−98	44	03.444

c. This program has the following limitations: In the Northern Hemisphere the EASTING vlaue must be between 50,000 and 900,000; the NORTHING value must be between 0 and 10,000,000. The program will accept only spheroid 1 if the Southern Hemisphere is selected; however, computations for the other spheroids may be carried out by converting the northing to the Northern Hemisphere coordinate system, computing as in the Northern Hemisphere, and changing the sign of the resulting latitude.

d. When the COMPUTE button is depressed, the program prints out the latitude (North (+); South (—))) and longitude (West (—); East (+)). The computational subroutines and formulas used produce results accurate to ± 0.003" in latitude and longitude.

13-17 ZONE TO ZONE TRANSFORMATION of Coordinates and Azimuth

a. Matrix position G-1 selects this program. Depressing the SM button causes the typeout of "ZONE TRANSFORMATION". The SET UP button is then depressed to erase any data previously entered and causes the same typeout.

b. Input data are as shown in the following example:

Matrix position	Input	Example	Remarks
G-2	*HEMISPHERE	+1	North (+1). Always enter +1. *Not valid in *Southern Hemisphere.*
G-3	SPHEROID REFERENCE	(1-5)	1. CLARKE 1866 2. INTERNATIONAL 3. CLARKE 1880 4. EVEREST 5. BESSEL
G-4	LOCAL UTM GRID ZONE NUMBER	14	
G-5	EASTING	675243.19	(2 decimal places)
G-6	NORTHING	3835473.76	(2 decimal places)
G-7	ADJACENT GRID ZONE NUMBER	15	
G-8	AZIMUTH Degrees Mils	30° .10' 39.630" 563.49200	(3 decimal places for seconds) (Up to 5 decimal places)

Printout of input:

1.	1.	14.	675243.19	3835473.76	15.	586.49200

Printout of solution:

1	1	15	125261.43	3841418.73	597.18859

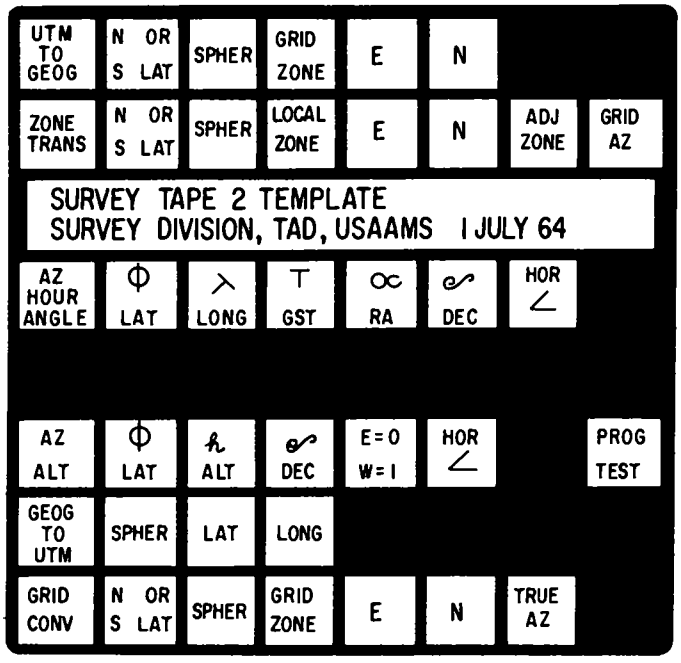


Figure 13-12. Matrix template—survey tape number 2.

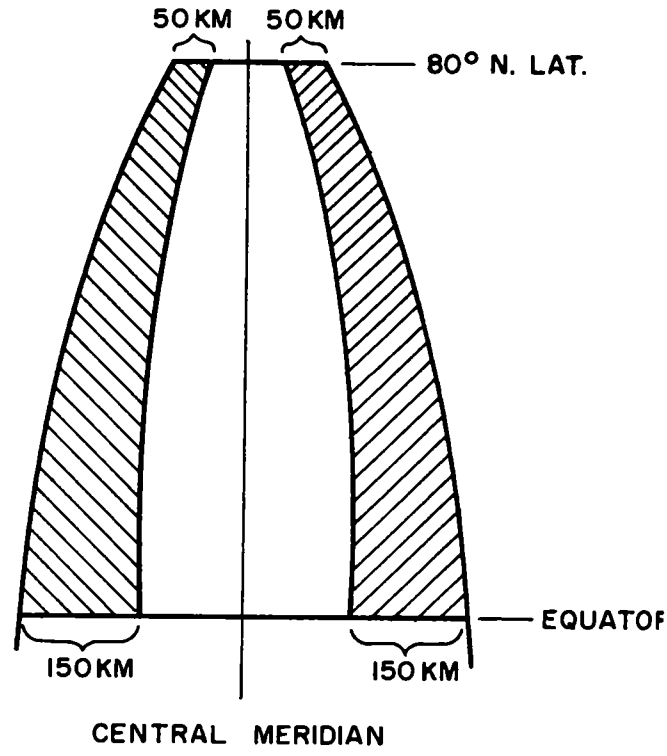


Figure 13-13. UTM grid zone.

c. When the COMPUTE button is depressed, this program prints out the spheroid reference (1 to 5), a new zone number, easting, northing and transformed azimuth. Zone-to-zone computations are limited to the nearest adjacent zone and to the shaded area as shown in figure 13-13. A central meridian cannot be crossed in any zone. This program destroys input data during the computation; therefore the SET UP button must be depressed and data must be reentered prior to any subsequent information.

d. Zone-to-zone computations for the Southern Hemisphere may be accomplished as follows:

(1) Subtract the northing from 10,000,000.00.

(2) Enter azimuth of zero (matrix position G-8).

(3) Perform the computation in the Norther Hemisphere by entering 1 (matric position G-2).

(4) Change the sign of the new grid azimuth and pply tshyis correction to the azimuth in the zone of origin. The easting and northing as printed out will be correct Southern Hemisphere coordinates.

13-18. AZIMUTH BY HOUR-ANGLE METHOD

a. The azimuth by hour-angle program is selected by depressing matrix button E-1. Depressing the SM key causes a printout of "AZIMUTH BY HOUR-ANGLE METHOD". The SET UP button is *not* used in this program.

b. Input data are entered as shown in the following example:

Matrix position	Input	Example	Remarks
E-2	LATITUDE Degrees	34° .39′ .47″	(Separate with decimals)
	Mils	616.237	(1-3 decimal places)
E-3	LONGITUDE Degrees	−98° .24′ .17″	(Separate with decimals)
	Mils	−1749.422	(1-3 decimal places)
E-4	GREENWICH SIDEREAL TIME Hours (Item 9, DA Form 6-10a; use GAT for sun, item 11, DA Form 6-10)	12^h .30^m .32^s	(Separate with decimals)
E-5	RIGHT ASCENSION OF STAR (Item 10, DA Form 6-10a; enter zero for sun)	02^h .33^m .33^s	(Separate with decimals)

Matrix position	Input	Example	Remarks
E–6	DECLINATION Degrees	15° .20′ .14″	(Separate with decimals)
	Mils	272.662	(1–3 decimal places)
	(Item 18, DA Form 6–10 and DA Form 6–10a)		
E–7	HORIZONTAL ANGLE Degrees	123° .44′ .21″	(Separate with decimals)
	Mils	2199.807	(1–3 decimal places)

Printout of input:

34	39	47.993	−98	24	17.953	12	30	32.000
2	33	33.953	272.66200		2199.80701			

Printout of solution:

2426.44744

13–19. AZIMUTH BY ALTITUDE METHOD

a. This program is selected by depressing matrix button C–1. Depressing the SM key causes a typeout of "AZIMUTH BY ALTITUDE METHOD". The SET UP button is *not* used in this program.

b. Input data are shown in the following example:

Matrix position	Input	Example	Remarks
C–2	LATITUDE Degrees	34° .39′ .47″	(Separate with decimals)
	(Item 18, DA Form 6–11)		
	Mils	616.237	(1–3 decimal places)
C–3	ALTITUDE Degrees	21° .01′ .32″	(Separate with decimals)
	Mils	373.788	(1–3 decimal places)
	(Corrected for parallax and/or refraction; item 11, DA Form 6–11)		
C–4	DECLINATION Degrees	15° .05′ .21″	(Separate with decimals)
	(Item 12, DA Form 6–11)		
	Mils	267.960	(1–3 decimal places)
C–5	STAR (SUN) E or W of observer's meridian	0 = East 1 = West	
C–6	HORIZONTAL ANGLE Degrees	242° .12′ .42″	(Separate with decimals)
	Mils	4305.985	(1–3 decimal places)
	(Item 36, DA Form 6–11)		

Printout of input:

34	39	47.990	373.78800	267.96000	0	4305.98498

Printout of solution:

3619.68612

Note. The astronomic azimuth programs have been written to accept emphemeris data and true altitude (corrected for parallax and/or refraction), thus making them valid for all stars and the sun for any current year and eliminating the need for using limited memory space with new ephemeris data each year for a restrictive number of stars. Computational subroutines yield results accurate to 02" (0.01 mil) for all possible situations. For the altitude method, the celestial body observed must be in such position that the altitude change per second is equal to or greater than the azimuth change per second; otherwise this method will not yield acceptable results.

c. Depressing the COMPUTE button causes solution of the problem in less than 1 second and the answer is immediately typed out in degrees or mils, depending on selection of button 1 or 2.

13–20. GEOGRAPHIC TO UTM COORDINATES

a. Matrix position B–1 selects this program. Depressing the SM key causes the program to type out "GEOGRAPHIC TO UTM". The SET UP button is then depressed to erase any data previously entered and causes the same typeout.

b. Input data are as shown in the following example:

Matrix position	Input	Example	Remarks
B–2	SPHEROID	1	1. CLARKE 1866 2. INTERNATIONAL 3. CLARKE 1880 4. EVEREST 5. BESSEL
B–3	LATITUDE + = north − = south	34° .36′ .42″ .098	(3 decimal places for seconds)
B–4	LONGITUDE + = east − = west	−90° .52′ .35″ .961	(3 decimal places for seconds)

Printout of input:

1. 34.36.42.098 −90.53.35.961

Printout of solution:

1 1 15 694689.95 3831836.06

c. When the COMPUTE button is depressed, the program prints out the hemisphere reference (±1), spheroid reference (1 to 5), UTM zone number (1–60), easting and northing.

d. This program has the limitation of latitude input of ±0° .5 to ± 80° .5. Spheroid 1 is the only spheroid which the program will accept if the Southern Hemisphere is selected; however, the other spheroids may be computed for the Southern Hemisphere by changing the sign of the latitude, computing in the Northern Hemisphere, and subtracting the resulting northing from 10,000,000.

13–21. GRID CONVERGENCE

a. Matrix position A–1 selects the grid convergence program. Depressing the SM key causes the program to type out "GRID CONVERGENCE". The SET UP button is then depressed to clear any previously entered data for this program, causing the same typeout.

b. Input data are as shown in the following example:

Matrix position	Input		Example	Remarks
A–2	HEMISPHERE		+1	+1 = Northern Hemisphere −1 = Southern Hemisphere
A–3	SPHEROID		1	1. CLARKE 1866 2. INTERNATIONAL 3. CLARKE 1880 4. EVEREST 5. BESSEL
A–4	UTM GRID ZONE NUMBER		14	(1–60 grid zones)
A–5	EASTING		555226.42	(2 decimals)
A–6	NORTHING		3835524.16	(2 decimals)
A–7	ASTRONOMIC AZIMUTH	Degrees Mils	162° .03′ .24″ .000 2881.00740	(3 decimal places for seconds) (Up to 5 decimal places for mils)

Printout of input;

1. 1. 14. 555226.42 3835524.16 2881.00740

Printout of solution;

−6.09418 2874.91822

c. When the COMPUTE button is depressed, the program prints out the amount of convergence and the grid azimuth (true azimuth plus grid convergence correction).

d. This program accepts UTM coordinates for all 5 spheroids in the Northern Hemisphere and for spheroid 1 in the Southern Hemisphere. The grid convergence correction may be computed for spheroids 2, 3, 4, and 5 in the Southern Hemisphere by changing coordinates systems, computing as in the Northern Hemisphere, and applying the convergence correction with opposite sign.

Section IV. CONVERSION

13–22. General

Both survey program tapes 1 and 2 provide the capability for converting mils to degrees, minutes, and seconds and vice versa.

13–22. Conversion of Mils to Degrees, Minutes and Seconds

To convert mils to degrees, minutes, and seconds—

a. Depress button 1.

b. Select a matrix position which designates input of a horizontal angle.

c. Depress SM key and enter angle in mils.

d. Depress button 2.

e. Depress RECALL button.

f. When the angle appears in the Indicator Display, depress the SEND button. The converted angle will then be typed out. (This step may be omitted if no typeout is desired.)

13–24. Conversion of Degrees, Minutes and Seconds to Mils

To convert degrees, minutes, and seconds to mils, use the same procedure as in paragraph 13–23, depressing button 2 and SM key before entering angle in degrees, minutes, and seconds. Depress butoon 1 and RECALL button for the indicator display and the SEND button for the typeout.

CHAPTER 14
BASIC ASTRONOMY

Section I. GENERAL

14-1. General

a. Modern weapon systems require an accurate direction from weapon to target. Providing the direction or azimuth is one of the primary missions of the artillery surveyor. The preceding chapters have shown how azimuth can be determined from existing survey control and the extension of azimuth through a traverse or triangulation scheme. These procedures, however, require considerable time and may result in possible loss of accuracy during the process of extending control. Correct grid azimuths can be determined accurately, rapidly and simply by the observation of the heavenly or celestial bodies (Sun & Stars). These observations, termed *astronomic observations,* furnish true azimuths which can be easily converted to correct grid azimuth by applying grid convergence.

b. Astronomic observations are made by the artillery surveyor to expedite the following survey operations:

(1) Determining a starting azimuth for a survey.

(2) Checking the closing azimuth of a survey.

(3) Checking the azimuth of any line in a survey.

(4) Providing orienting azimuths for cannons and associated fire control equipment.

(5) Providing orienting azimuths for missiles and associated guidance equipment.

(6) Determining azimuths for the declination of aiming circles.

14-2. The Earth

a. The earth has the shape of a flattened sphere. The line connecting the flattened ends of the earth is the earth's rotating axis, and the points at either end of this axis are called the north and south poles, respectively.

b. The earth *rotates* on its axis from west to east, making one complete rotation in a period of approximately 24 hours. As the earth rotates, it also *revolves* about the sun in an elliptical orbit, making one complete revolution each year. If the earth's axis were perpendicular to this elliptical orbit, the sun's rays would be directed at the Equator throughout the year which would result in no change in seasons. Because the axis is tilted at an angle of approximately 23° 30′ (417.78 mils) from the perpendicular to this elliptical orbit, as the earth revolves about the sun, the rays of the sun are directed at different portions of the earth.

c. Since a rectangular coordinate system cannot be adapted to a sphere, a system utilizing angular measurements was adopted.

(1) *Longitude.* Planes were passed through the earth so they intersect at both poles. The lines which these planes inscribe on the surface of the sphere are called *meridians of longitude.* A base line for measurement was established when the meridian that passed through Greenwich, England, was given a value of 0°. Longitude is measured in units of degrees, minutes and seconds both east and west of the Greenwich meridian. Longitude is identified as being east or west (i.e., 90° 24′ 18″ W or 40° 12′ 43″ E).

(2) *Latitude.* Other planes were also passed through the earth, all parallel to each other and perpendicular to the earth's rotating axis. The lines inscribed on the earth's surface by these planes are called *parallels of latitude.* The parallel of latitude halfway between the poles is called the Equator. This parallel is given a value of 0° and is used as the basis for measurement of latitude. Latitude is measured in units of degrees, minutes, seconds north or south of the equator (i.e., 34° 48′ 12″ N or 30° 12′ 16″ S).

14-3. The Celestial Sphere

The celestial bodies seem to be fixed on the inside of a spherical surface, the center of which is the

earth. This spherical surface is called the *celestial sphere.* This *celestial sphere* includes not only the hemisphere above the horizon but also the hemisphere below. The radius of the sphere can be assumed as infinite, since the bodies are so far away. The celestial sphere is only apparent, for some of the bodies are relatively near and others are far away.

14–4. Solar System

a. The *solar system* consists of the sun, planets, and their satellites, asteroids, comets and meteor swarms moving under the gravitation of the sun.

b. The earth and its motions are of primary interest to the surveyor. The motions of the earth form a complex pattern, all of which affect the earth's relationship to the stars and other planets. First, with respect to the stars and not the sun, the earth *rotates* on its axis in 23 hours and 56 minutes rather than in 24 hours. Second, the earth revolves in its orbit around the sun once a year. Third, the earth's axis has a cone-shaped motion, or precession, making one turn in about 25,800 years. Fourth, the North and South Poles are not stationary but wander in rough circles about 40 feet in diameter. Finally, there is a solar motion of 12 miles per second, while the earth's part of the galaxy seems to be whirling through space at 170 miles per second. Of the five motions involving the earth, rotation and revolution are of most importance to the surveyor.

(1) *Rotation.* Rotation refers to the turning of a body on its axis. The terminal points of the axis of the earth are the North and South poles. The rotation is from west to east (fig 14–1).

(2) *Revolution.* The earth revolves about the sun on a 600-million-mile orbit at a speed of about 18.5 miles per second. In practical astronomy, it is assumed that the earth is stationary and that the celestial bodies move about it from east to west on the celestial sphere (fig 14–2).

14–5. Time

a. Since the rotation period of the earth is quite uniform, it is an excellent timekeeper. This rotation period has been employed to establish a basic unit of time, the day, which is the time required by the earth to complete one rotation.

b. When this basic unit of time is used with respect to the stars, it is known as a *sidereal day.* In respect to the sun, this basic time unit is called *solar day.*

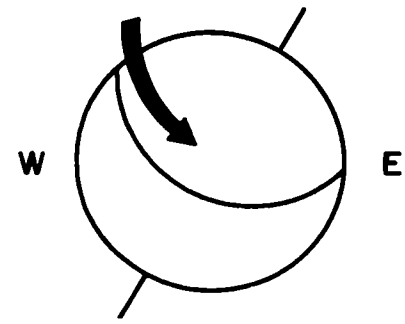


Figure 14–1. Rotation of the earth.

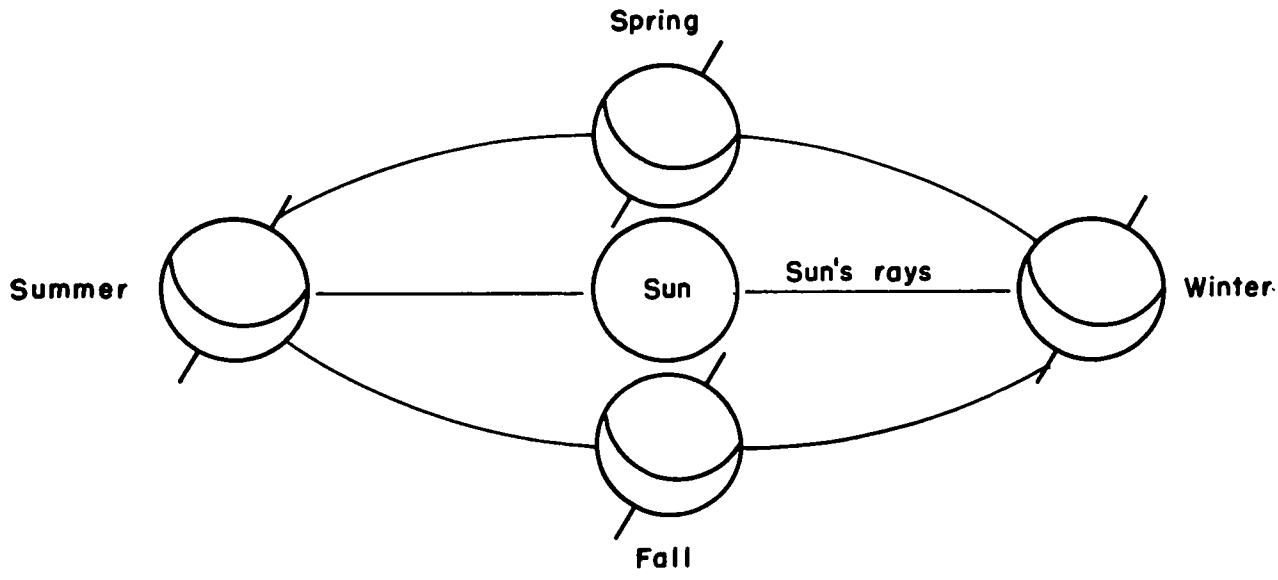


Figure 14–2. Revolution of the earth about the sun.

c. Since the earth rotates 360° in 13 hours mean time, it moves 15° in 1 hour; therefore, time changes 1 hour for every 15° of longitude (fig 14–3). The prime meridian, which passes through the Greenwich Observatory, London, England, is the starting point, and all time is computed with respect to this meridian. At a point 15° west of Greenwich, the time is 1 hour earlier, since the sun passes the Greenwich meridian 1 hour before it passes the 15° west meridian. The opposite would be true for a point 15° east of Greenwich.

d. Time changes 1 hour for each 15° of longitude. Each 15° meridian east and west of Greenwich is called a standard time meridian of a time zone. Each time zone extends 7½° east and west of the standard meridian. For example, the time zone of the 90° meridian extends from 82½° to 97½° (fig 14–4).

14–6. Solar Time

a. Apparent Solar Time. In general, we say that it is apparent noon when the sun is on the observer's meridian and that a solar day is the interval of time between two successive passages of the sun across the meridian. Time measured in this way (by a sundial) is called apparent solar time. Since it is customary to begin the calendar day at midnight, the apparent solar time at any instant is equal to the hour angle of the sun plus or minus 12 hours. The apparent solar time, however, is not adapted to modern conditions, for the apparent solar days vary in length. Thus, 25 December is 50 seconds longer than 13 September, and the days in January average 15 seconds longer than the days in July. The length of the apparent solar day varies because the sun moves along the *ecliptic* (apparent path of the sun) and not along the *celestial equator* and because this movement along the ecliptic is not uniform.

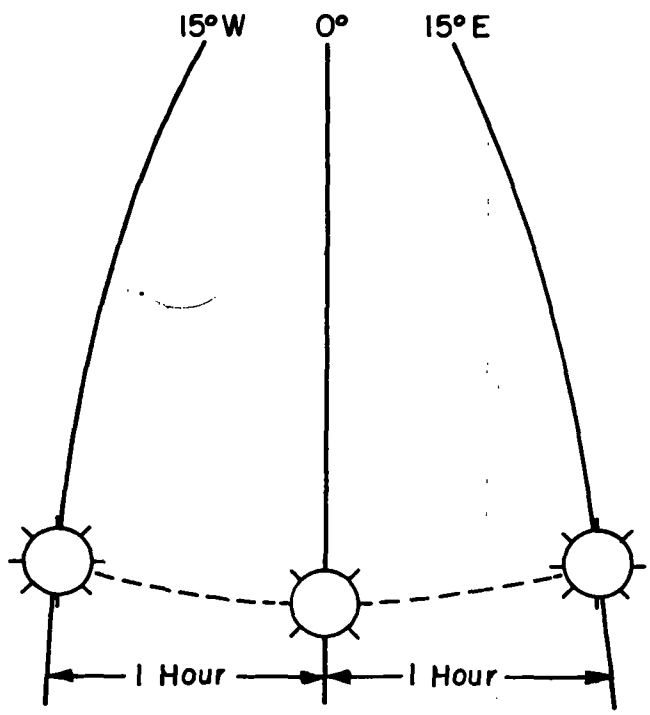


Figure 14–3. Apparent motion of the sun.

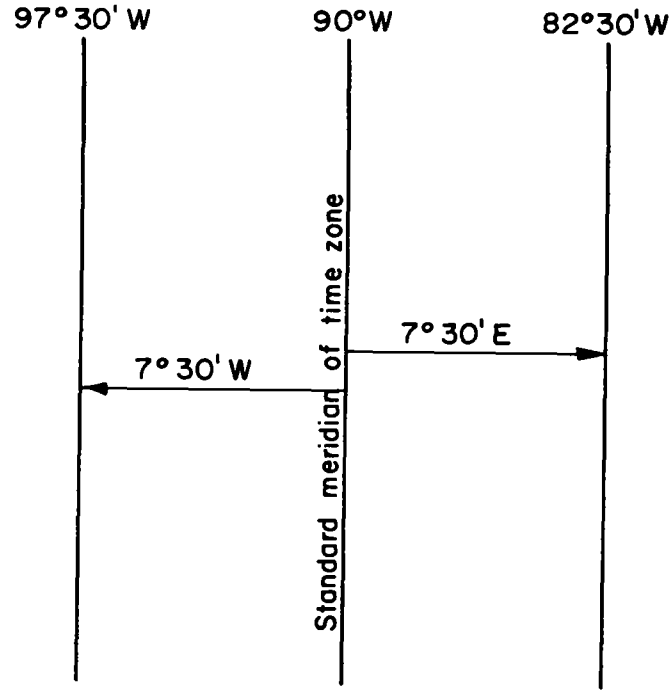


Figure 14–4. Time zone boundaries.

b. Mean Solar Time. Since the solar day varies in length, a day of uniform length, called the mean solar day, has been devised with hours numbered from 0 to 24. This day is measured by a fictitious sun, called the *mean sun*, which moves uniformly along the celestial equator. Mean solar noon occurs when the mean sun is on the observer's meridian.

c. Equation of Time. The difference between apparent time and mean time is known as the equation of time. This difference varies from plus 16 minutes to minus 14 minutes (fig 14–5).

14–7. Sidereal Time

a. Sidereal time is based on the rotation of the earth with respect to the stars. The sidereal day is the interval of time between two successive upper transits of the vernal equinox (point of intersection of the ecliptic and celestial equator occupied

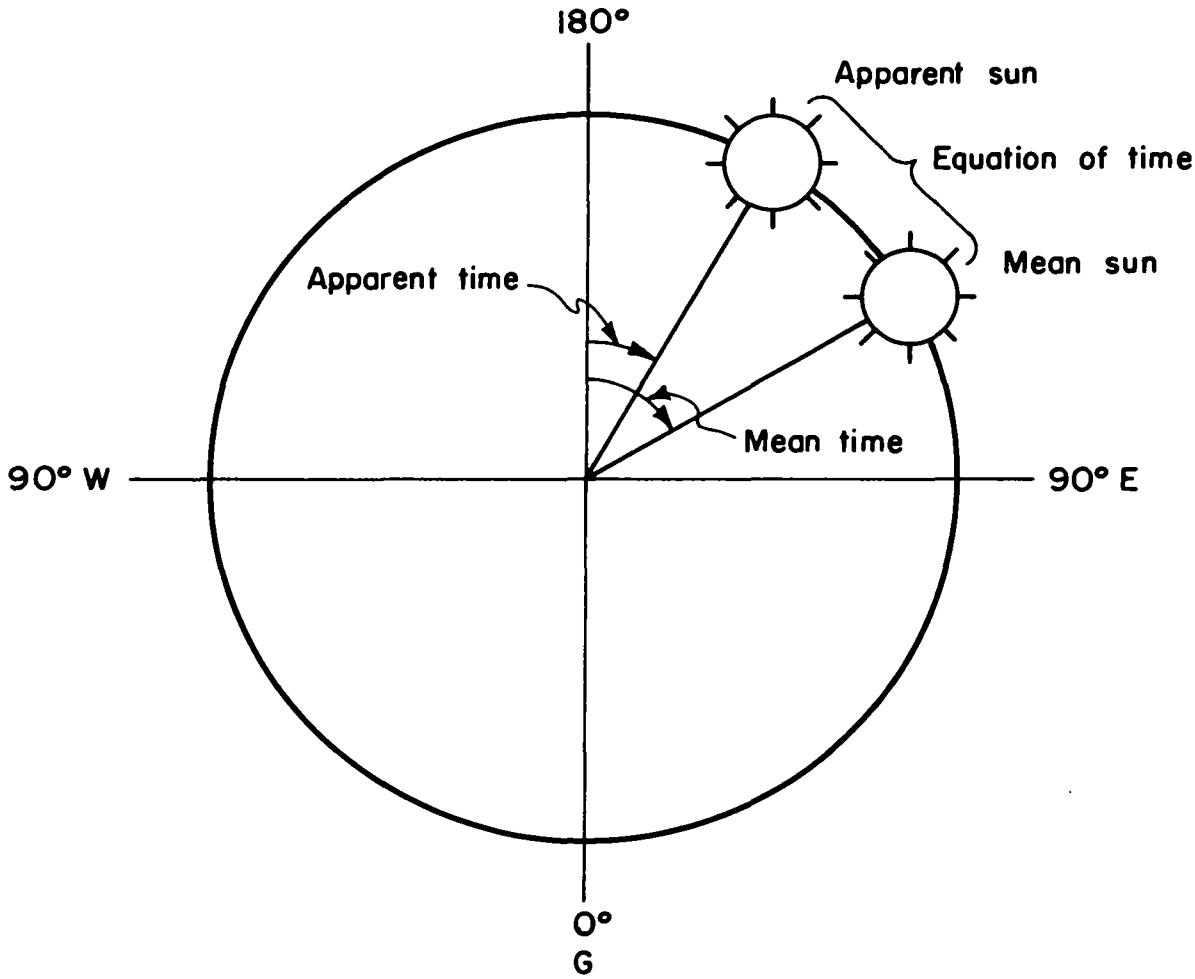


Figure 14–5. Mean and apparent solar time.

by the sun as it changes from southern to northern declination) over the same meridian. Since the upper transit of the vernal equinox designates the beginning of the sidereal day (Sidereal Noon) it differs from the beginning of a solar day designated by the lower transit of the sun across the meridian (Solar Midnight). The sidereal time at any instant is the number of hours, minutes and seconds that have elapsed since the last upper transit of the vernal equinox and may be expressed as the hour angle of the vernal equinox (fig 14–6).

b. The annual apparent motion of the sun along the ecliptic is opposite in direction to its daily path. Consequently, the relationship between solar time and sidereal time is variable. For example, on 21 September at the instant the vernal equinox crosses the observers meridian, the mean sun is crossing the lower branch of the observers meridian. At this instant, the sidereal clock of the observer will read $0^h0^m0^s$ and the civil clock will read $0^h0^m0^s$. Twenty-four sidereal hours later, the vernal equinox will again cross the observers meridian, but the mean sun will not yet have crossed the lower branch of the meridian. From this, we observe the civil clock reads about 23^h56^m which shows the sidereal clock gains on the civil clock about 4^m per sidereal day. This interval is accumulated throughout the tropical year so that it contains 365.24 civil days and 366.24 sidereal days. Sidereal time is used primarily for the computation of astronomic observations.

14–8. Astronomic Triangle

a. Determining azimuth by astronomic observation involves the solution of a spherical triangle visualized on the celestial sphere (fig 14–7). The desired result, the azimuth angle, is one of the angles of this triangle. The value of the angle can be computed when certain other parts of the triangle are known. The astronomic triangle is called

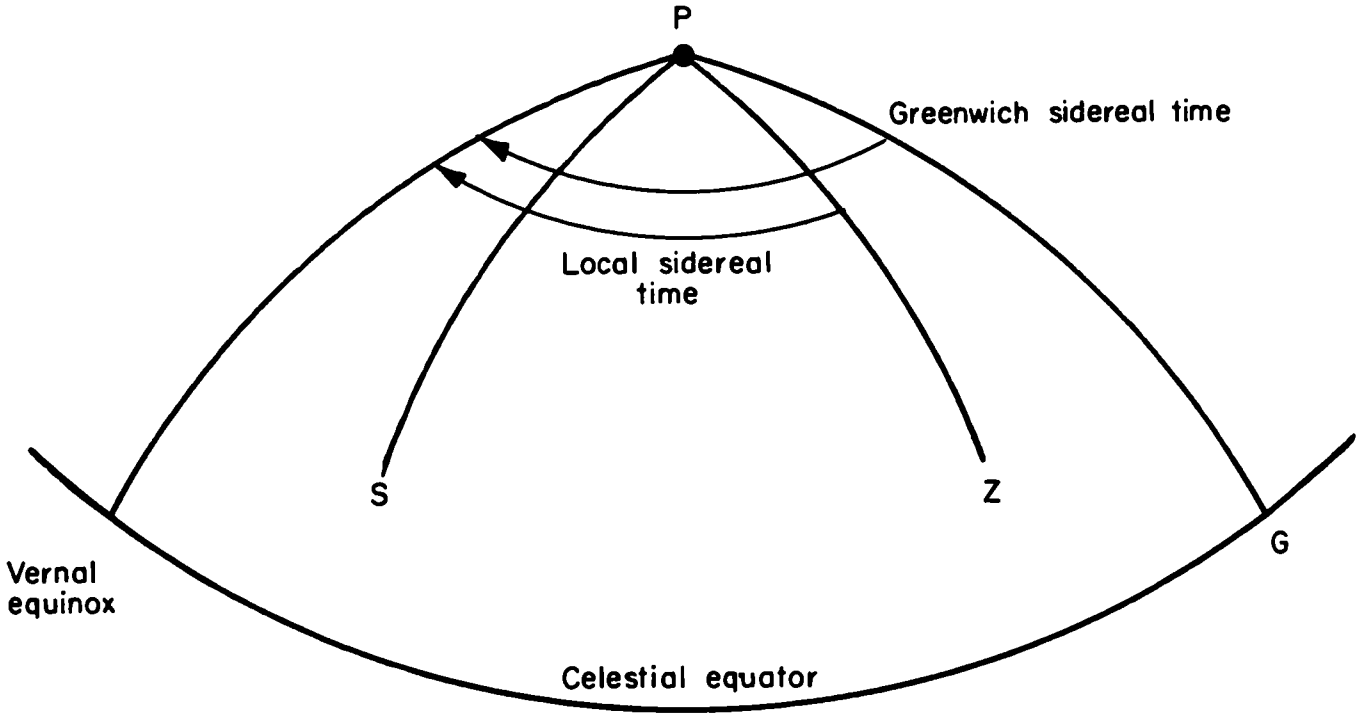


Figure 14–6. Sidereal time.

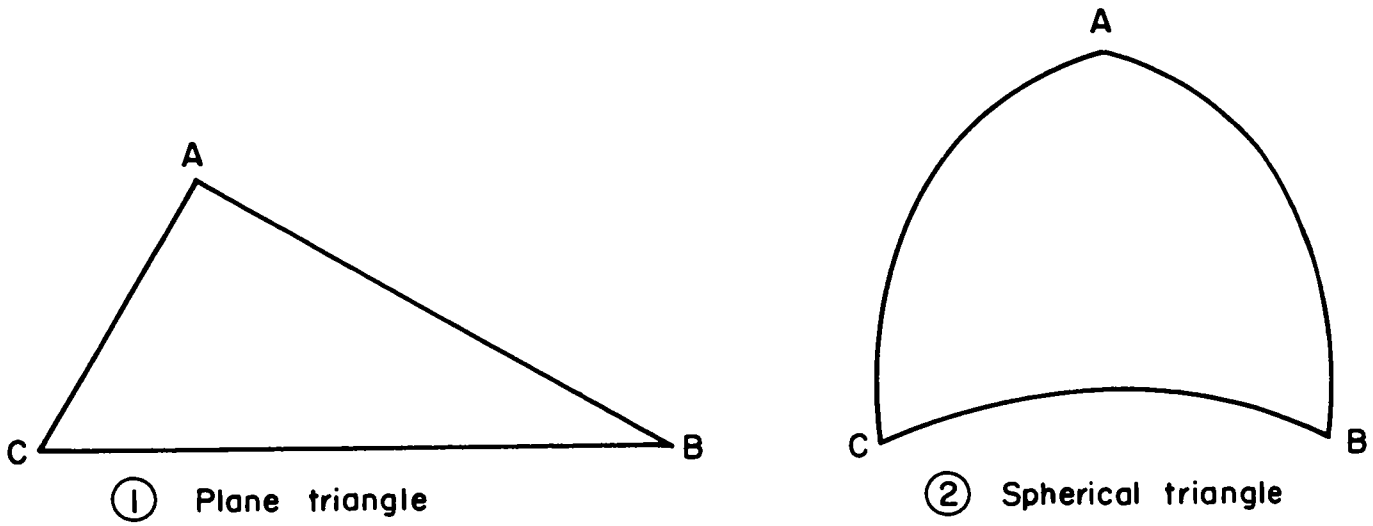


Figure 14–7. Plane and spherical triangles.

the *PZS* triangle. These letters represent the three vertexes; namely, the *pole*, the *zenith*, and the *star* (or celestial body). The PZS triangle is constructed by using several known references which can be extended to the celestial sphere.

b. The P, or pole, of the triangle is described as that point on the celestial sphere where an extension of the earth's North Pole would intersect the celestial sphere. It is then called the *celestial north pole* (fig 14–8).

c. The *zenith* on the celestial sphere is that point where an upward extension of the observer's plumb line would intersect the celestial sphere (fig 14–9).

d. The celestial body observed, either sun or

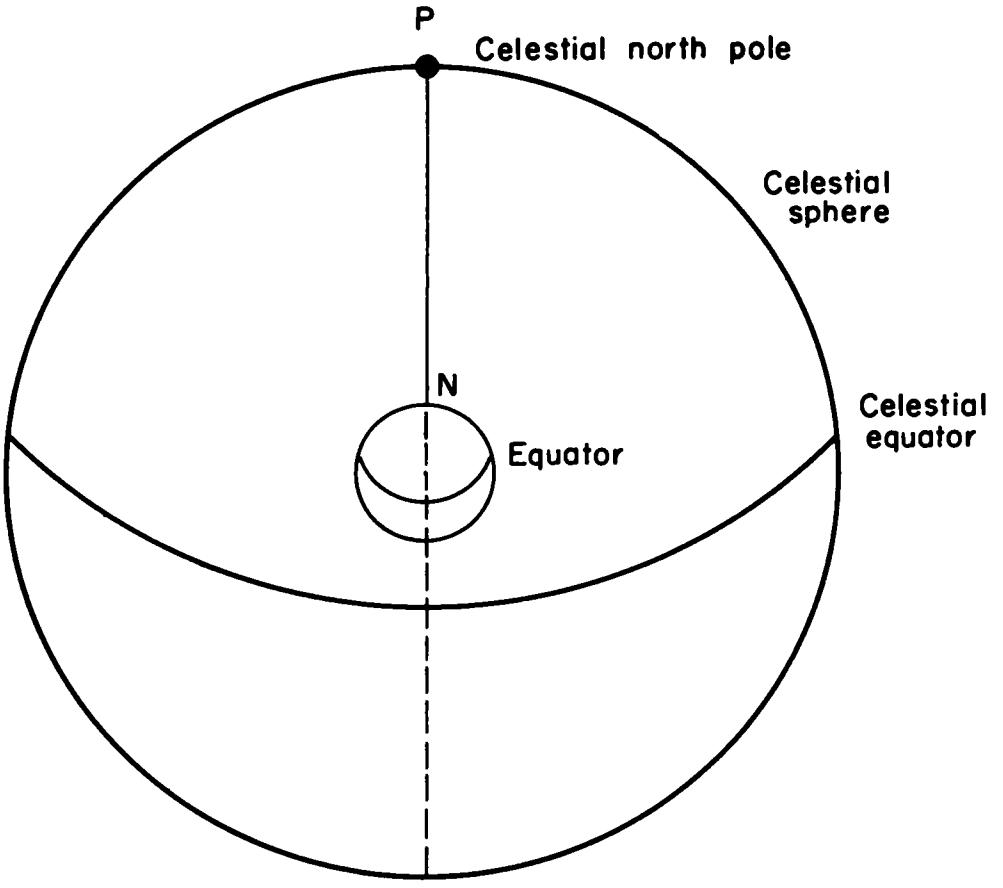


Figure 14–8. Celestial north pole.

star, makes the third point of the celestial triangle (fig 14–10).

e. Since the points of the astronomic triangle cannot be occupied, as in triangulation, measurements which can be made on earth must be projected to the celestial sphere to solve the triangle.

f. The angles of the PSZ triangle (fig 14–11) are referred to by name. The interior angle at the celestial north pole between the zenith and the celestial body is called the *hour angle* designated "t". The local hour angle represents the time that has elapsed since the celestial body crossed the observer's meridian. The angle at the zenith between the celestial north pole and the celestial body is called the *azimuth angle* and is the angle computed to determine true azimuth from the observer to the celestial body. When the celestial body is in the east, the azimuth angle is equal to true azimuth; when the celestial body is in the west, 6400 mils minus the azimuth angle equals true azimuth. The third angle is the angle at the celestial body between the celestial north pole and the zenith. This angle is called the parallactic angle. The *parallactic angle* is used in determining azimuth but is canceled out in the computations.

14–9. Celestial Equator

a. The plane formed by the earth's equator when extended to the celestial sphere describes the *celestial equator* (fig 14–12). Thus, as the earth's equator is the midpoint between the North and South Poles, the celestial equator is the midpoint between the celestial north and south poles. The celestial equator is used as a reference in determining the sides of the celestial triangle.

b. Latitude on earth is described as the angular distance of a station along its meridian from the equator. Since the station and the equator are extended to the celestial sphere in the form of the zenith and celestial equator, respectively, latitude is shown on the celestial sphere as the angular distance from the celestial equator to the zenith. The angular distance from the celestial equator to the North Pole is 90°; likewise, the angular distance on the celestial sphere from the ce-

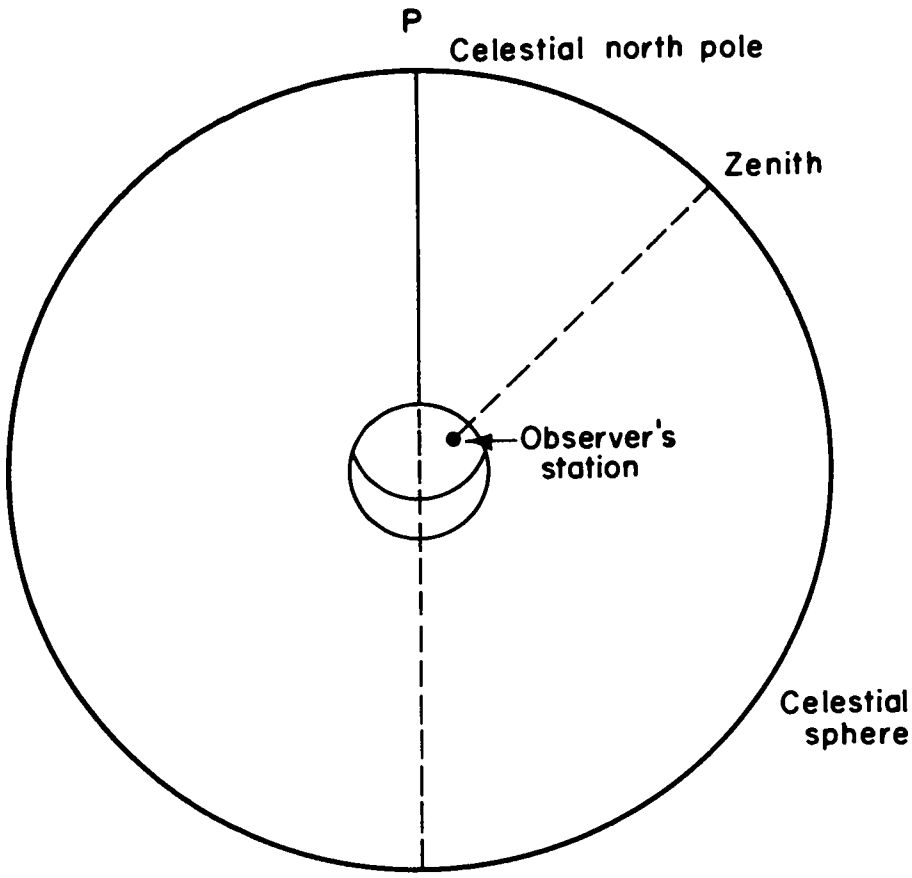


Figure 14-9. Observer's zenith.

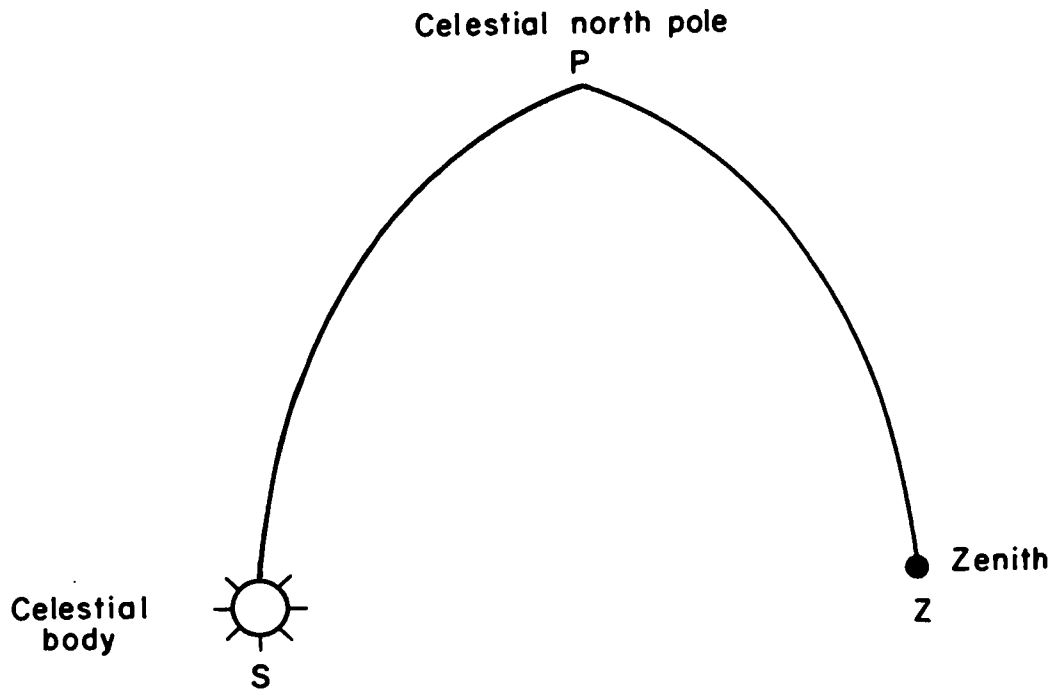


Figure 14-10. Celestial body with respect to zenith and celestial pole.

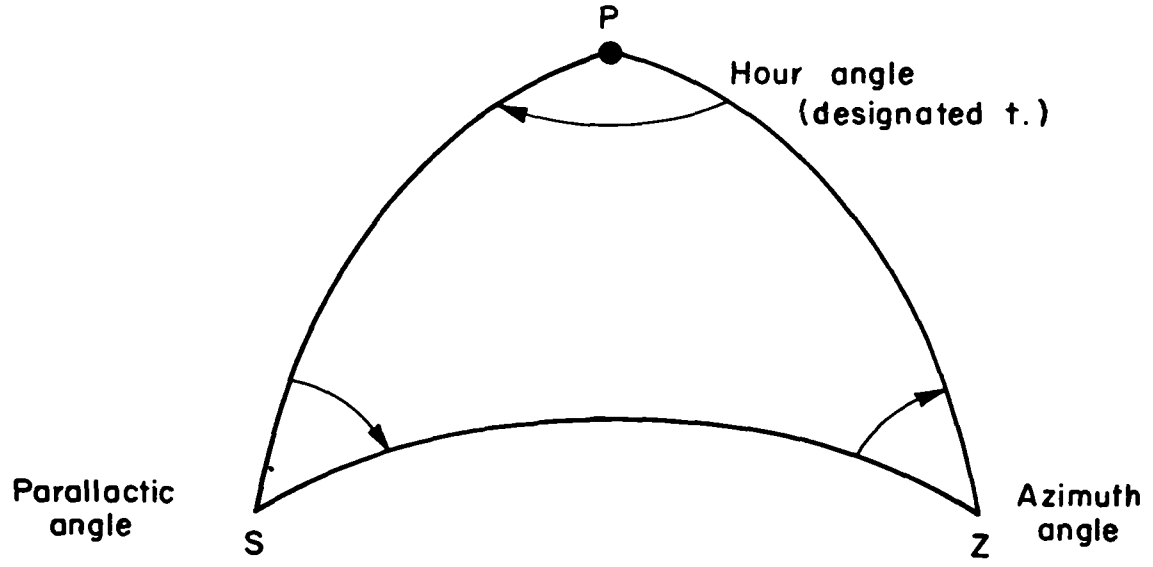


Figure 14–11. Angles of the PZS triangle.

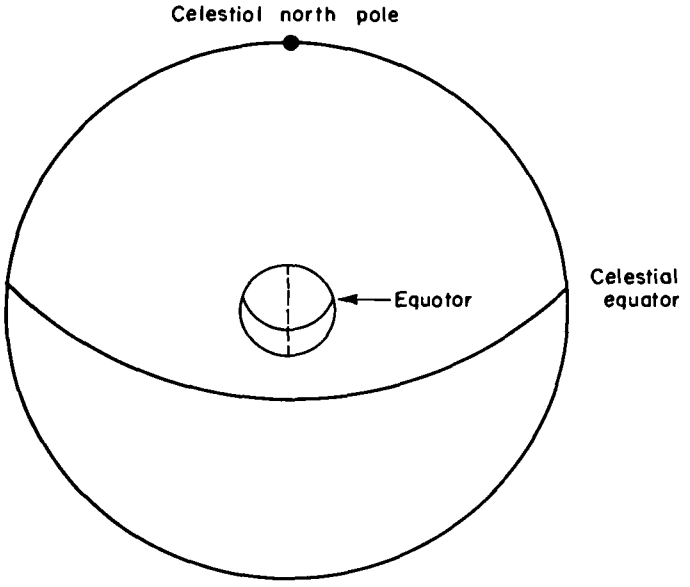


Figure 14–12. Celestial equator.

lestial equator to the celestial north pole is 90°. With this known value and the value of latitude, one is able to determine the side PZ of the PZS triangle by subtracting the north latitude from 90° or by adding the south latitude to 90°. The resulting side, PZ, is called the *colatitude* (fig 14–13).

c. The side of the PZS triangle from the celestial north pole to the celestial body is called the *polar distance* (fig 14–14). The value of the side PS, polar distance, is determined from the declination of the celestial body observed. *Declination* may be defined as the angular distance from a celestial body to the celestial equator. When the body lies north of the celestial equator, its declination has a positive sign; when south of the celestial equator, a minus sign. Declination of a body may be compared to the latitude of a station, since the angular distance from the celestial equator is involved in both cases. As pointed out in *b* above, the angular distance from the celestial north pole to the celestial equator is 90°; hence, when the declination of the body is known, the side P to S of the PZS triangle can be computed. When the declination is positive, the side PS is determined by subtracting the declination from 90°; when negative, by adding 90° to the declination and disregarding the sign.

d. The side of the PZS triangle from the celestial body to the zenith is called *coaltitude*. The value of coaltitude is determined from the altitude of the celestial body. The *altitude* of a body is the angular distance on the celestial sphere from the observer's horizon to the body (fig 14–15). The observer's horizon can be described as the arc cut on the celestial sphere by the extension of a plane tangent to the earth at the observer's station. This reference can be visualized by placing a vertical angle of 0° on an instrument and traversing the instrument through 360°. The line of sight thus described is the observer's horizon. From the observer's horizon to the zenith is 90°. The value of S to Z, the coaltitude, is determined by subtracting the altitude of the celestial body from 90°.

14–10. Methods of Determining Azimuth

The artillery surveyor uses three basic methods to

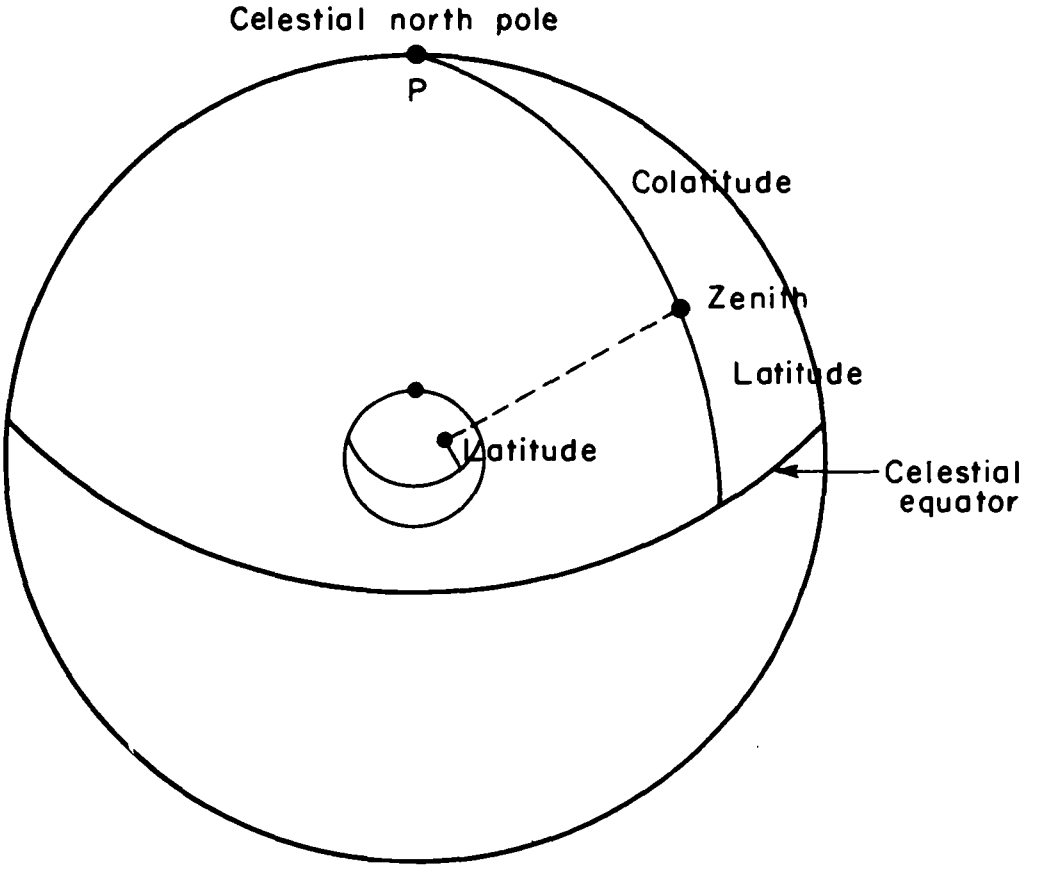


Figure 14–13. Latitude projected to the celestial sphere.

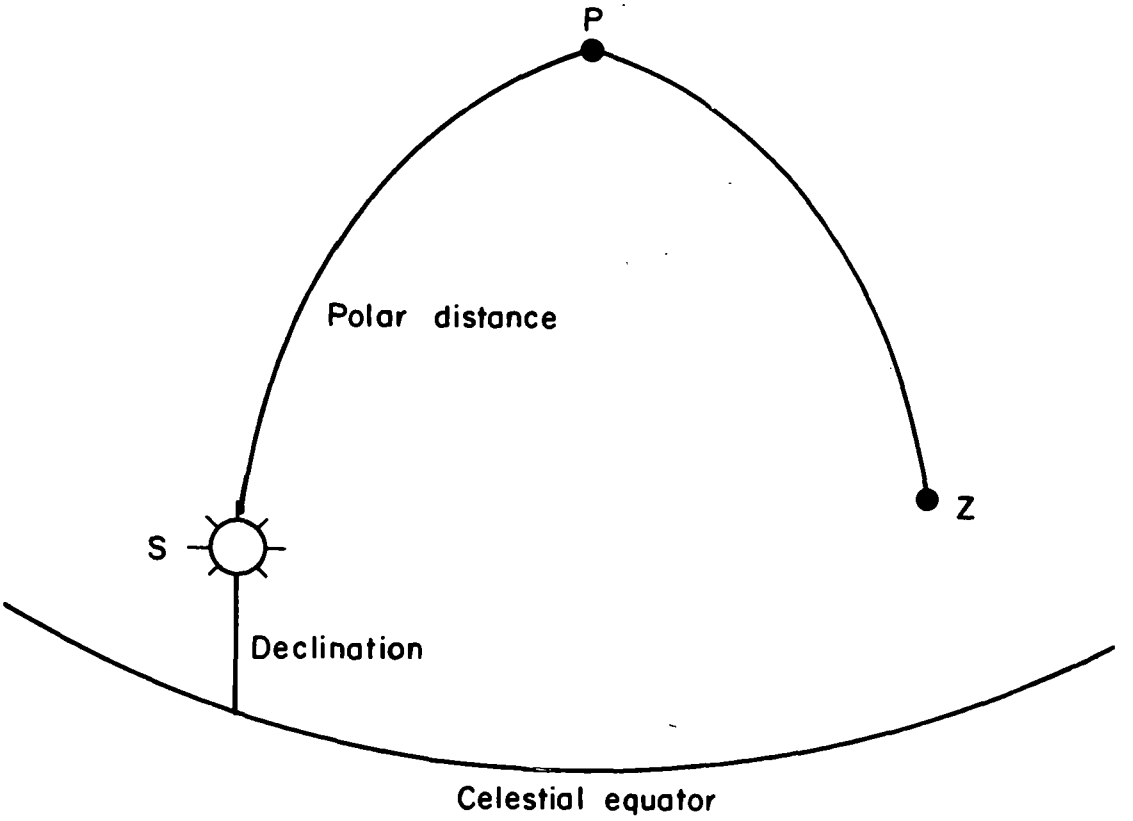


Figure 14–14. Declination of body on celestial sphere.

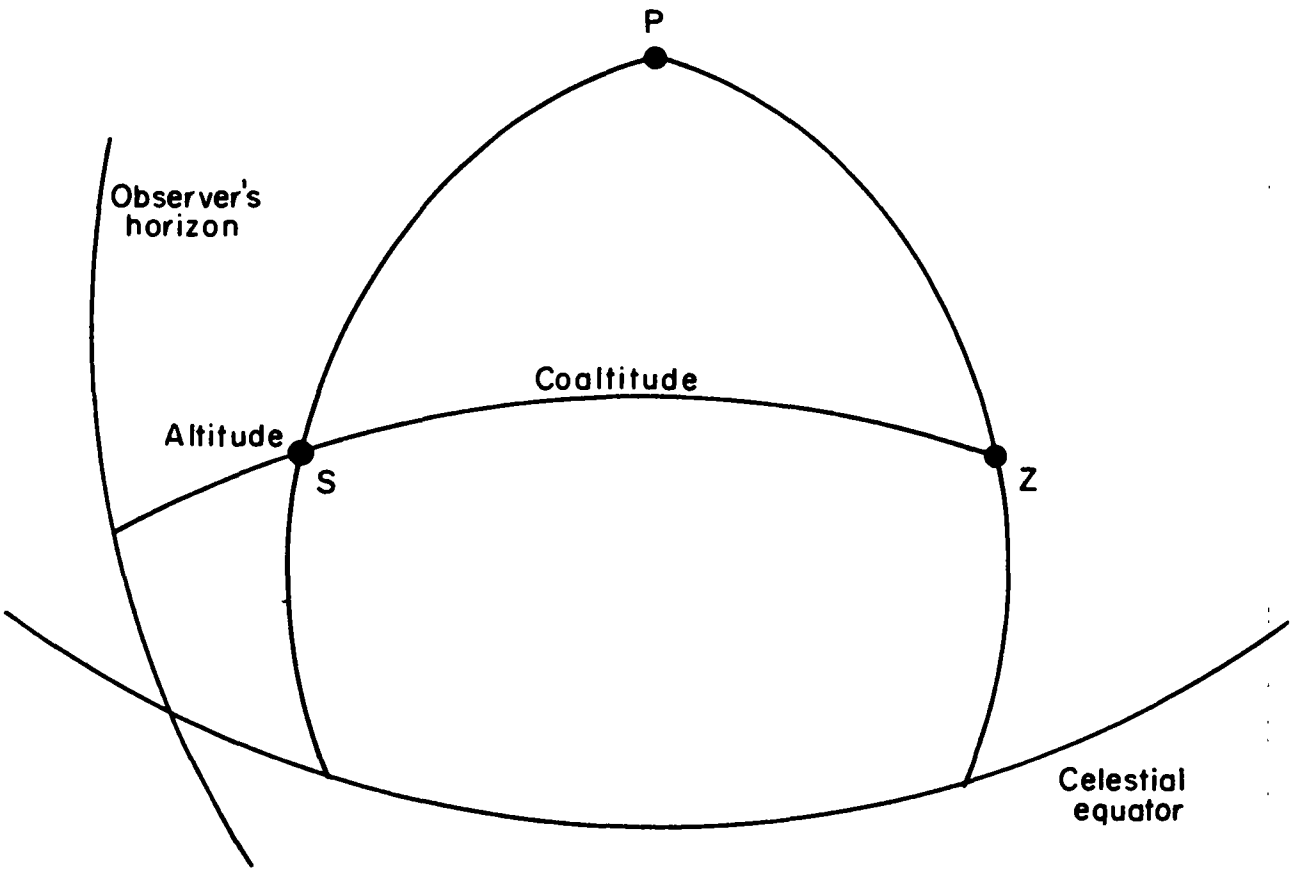


Figure 14-15. Observer's horizon and altitude of celestial body.

determine azimuth by astronomic observation—the altitude method, the hour-angle method, and the Polaris tabular method. The altitude method and the hour-angle method can be used with the sun or the stars and involve solving the PSZ triangle for the true azimuth to the observed body. The Polaris tabular method involves extracting a corrected azimuth to Polaris from a table in the Army Ephemeris. All three methods require a horizontal angle from an azimuth mark to the observed body to materialize the astronomic azimuth on the ground.

a. In the *altitude method* (fig 14-16), the PZS triangle is solved by using the known data—the three sides of the triangle. In addition to the angle from a ground point to the celestial body, three elements must be determined. These elements are the latitude for determining the side coaltitude, the declination of the body for determining the side polar distance, and the altitude for determining the side coaltitude.

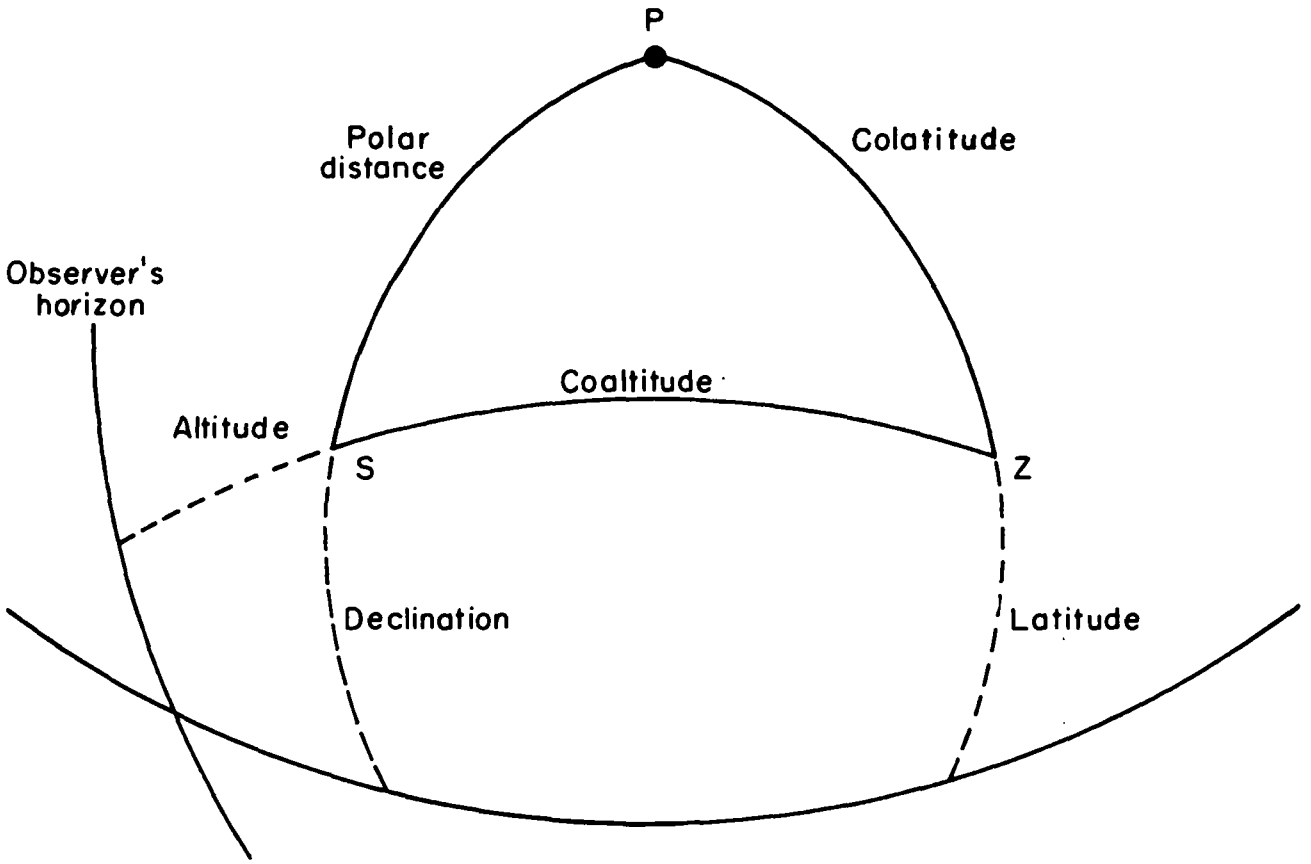


Figure 14-16. Altitude method of solving the PZS triangle.

b. In the *hour-angle method* (fig 14-17), the azimuth angle is determined from two sides and the included angle. The sides are the polar distance and colatitude and must be determined as in paragraph 14-9*b* and *c*. The angle is the local hour angle. The value of the local hour angle is computed by using the time of the observation.

c. In the *Polaris tabular method,* the azimuth to Polaris is tabulated in the Army Ephemeris for every 3 minutes of local sidereal time. The listed azimuth is corrected for the observer's latitude and the date of observation. This method avoids lengthy PZS triangle solutions, but it can be used only at night, in the Northern Hemisphere, for fifth-order azimuths.

d. Each method of determining azimuth is discussed in detail in paragraphs 14-31 through 14-50.

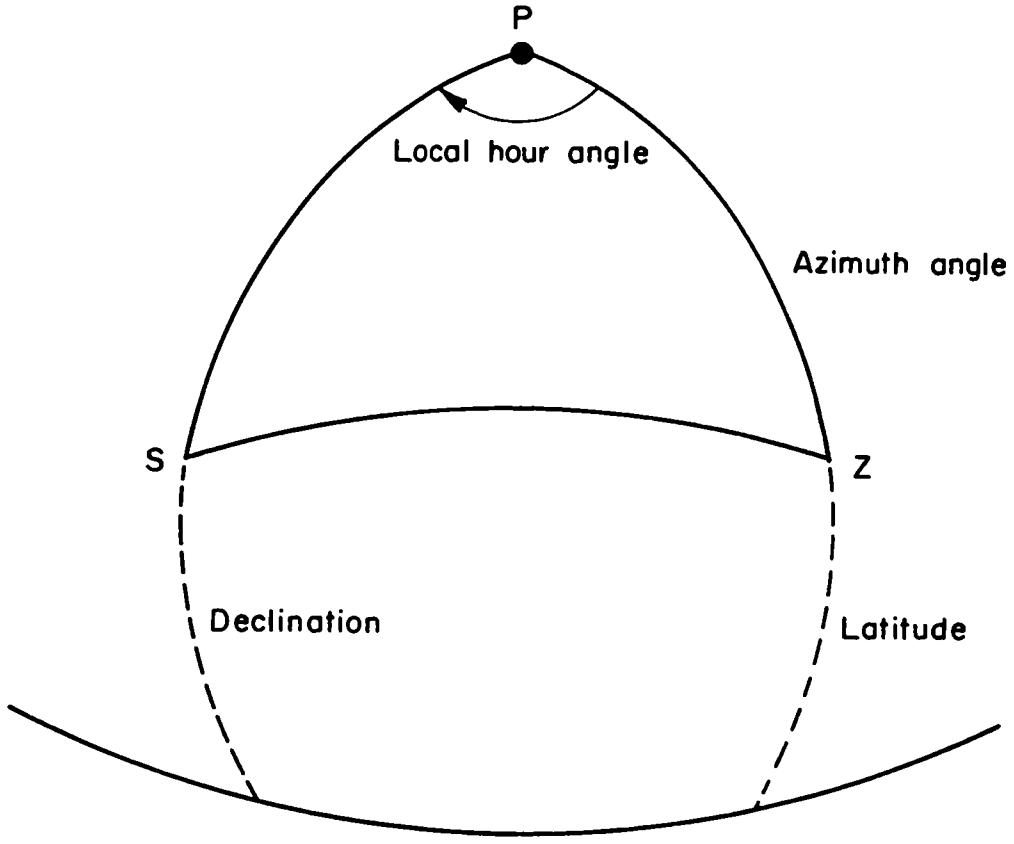


Figure 14–17. Hour-angle method of solving the PZS triangle.

Section II. TECHNIQUES OF OBSERVING

14–11. Field Requirements for Astronomic Observations

Each of the three methods of determining azimuth by astronomic observations requires the measurement of the horizontal angle from the azimuth mark to the celestial body, with the measurement of the vertical angle also required for the altitude method (fig 14–18). Except for the method of pointing on the celestial body, horizontal and vertical angles are measured in the same way that angles are measured in traverse, with a set of observations consisting of horizontal angles measured one position and vertical angles measured one direct and reverse.

14–12. Star Observations

When viewed through a theodolite, a star appears as a moving pinpoint of light, and special techniques for pointing the instrument are required for astronomic observations. Before beginning a series of observations, the instrument operator should study the apparent motion of the selected star through the instrument telescope to become familiar with the direction and rate of the apparent motion of the star.

a. Altitude Method. For astronomic observations by the altitude method, the initial pointing on the azimuth mark is made with the telescope in the direct position. The horizontal circle reading is recorded, and then the telescope is pointed toward the selected star. To make the pointing on the star, the instrument operator places the intersection of the single vertical crossline and the horizontal crossline just ahead of the apparent path of the star. The star then moves into the intersection by its own apparent motion (fig 14–19). As the star approaches the intersection, the instrument operator calls READY and, at the instant that the intersection bisects the star, TIP, and the recorder notes and records this instant of time, along with the horizontal and vertical circle readings. The telescope is reversed, a second pointing is made on the star, and again the time and circle readings are recorded. The instrument, with the telescope still in the reverse position, is then pointed to the azimuth mark and the horizontal circle reading is

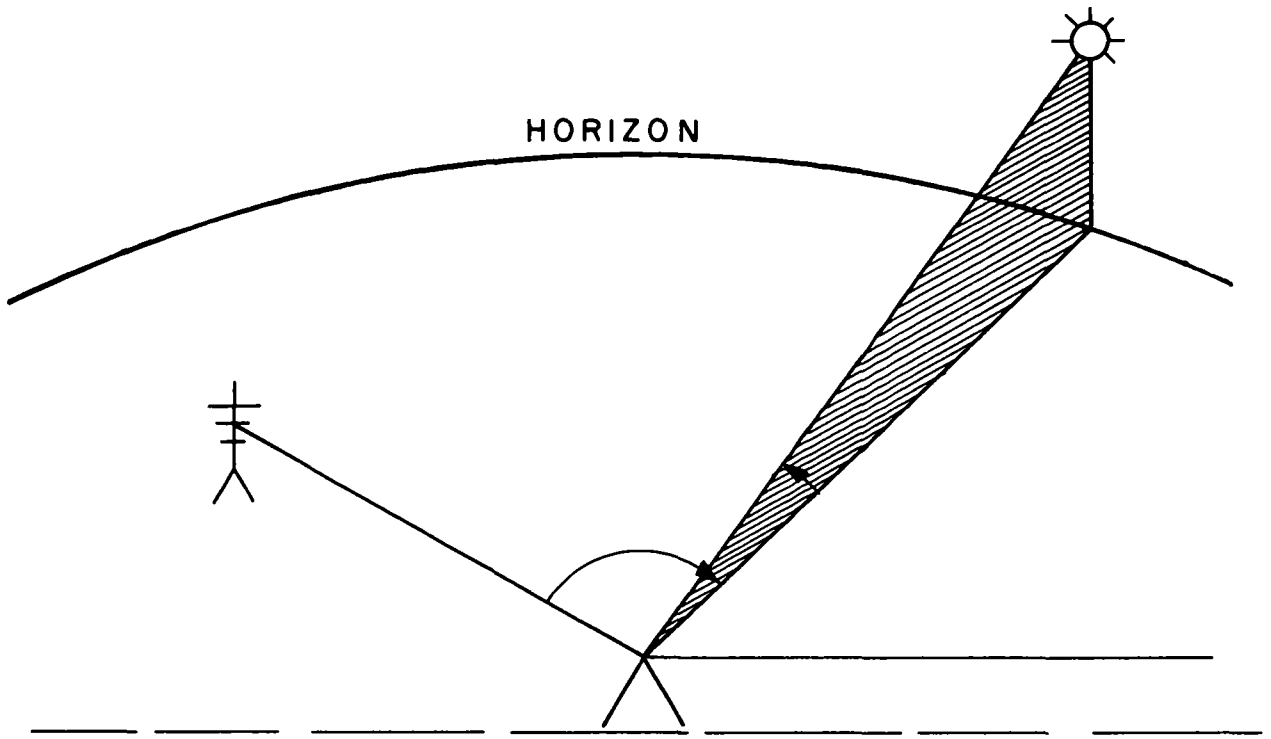


Figure 14-18. Measuring horizontal and vertical angles from azimuth mark to celestial body.

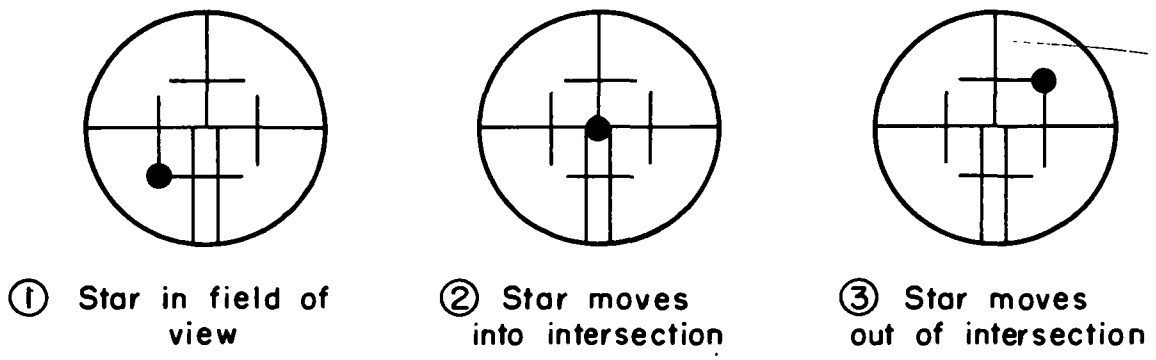


Figure 14-19. Sighting on a star.

again recorded to complete one position. Rather than position the telescope and let the stars apparent motion bring it to the center of the reticle, some observers prefer to bisect the star with one of the crosslines in the vicinity of their intersection and track it along this crossline with the appropriate tangent screw while the star's apparent motion brings it into the intersection.

b. Hour-Angle Method. The procedures for observing a star for the hour-angle method are generally the same as for the altitude method. However, since there is no requirement to measure the vertical angle for the hour-angle method, the single vertical crossline is placed just ahead of the apparent path of the star so that the star will reach the vertical crossline in the vicinity of its intersection with the horizontal crossline. Extra care must be used in noting and recording the exact time that the vertical crossline bisects the star, since this time is a critical element in the hour-angle method.

c. Polaris Tabular Method. The procedures for observing Polaris by the tabular method are the same as those for hour-angle observations, except that exact time is not so critical.

14–13. Sun Observations

Measuring angles to the sun presents special problems, since the sun is relatively near the earth and appears as a disk with a diameter of about 9.5 mils. When the sun is viewed through a theodolite with an inverted-image telescope, the apparent motion of the sun will be opposite to the motion as seen with the naked eye. Also, *care must be exercised to avoid viewing the sun through a telescope not equipped with a sun filter to avoid serious injury to the eye.*

a. Observations Using the Solar Circle. As an aid for measuring horizontal and vertical angles to the center of the sun, a solar circle is included as a part of the reticle pattern (fig 14–20) on some theodolites. The diameter of the solar circle is equal to the mean apparent diameter of the sun; hence, in the summer months, when the sun is more distance from the earth, the sun will not quite fill the solar circle; whereas, in the winter, when the sun is nearer the earth, the sun appears to slightly overlap the solar circle. To make the pointing, the instrument operator tracks the sun with both the horizontal and vertical tangent screws until it is perfectly centered in the circle, at which time he announces TIP and reads the circles.

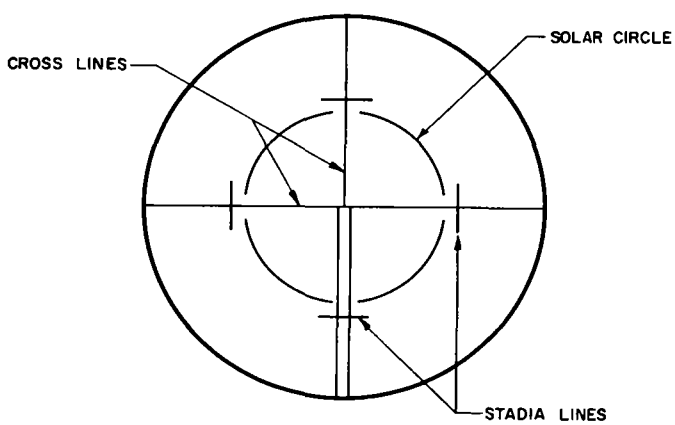


Figure 14–20. Solar circle.

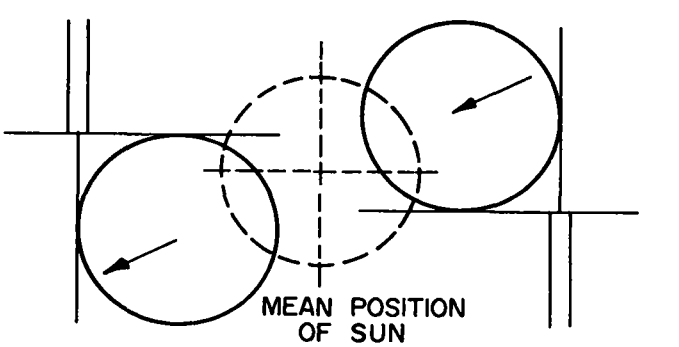
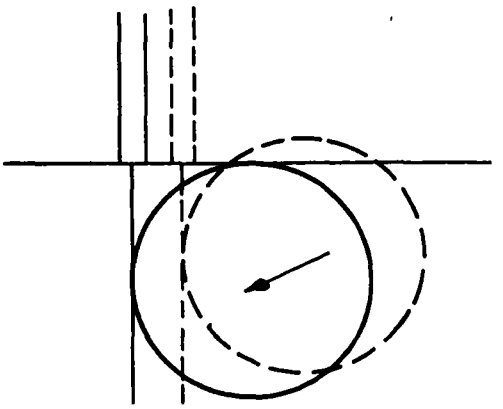


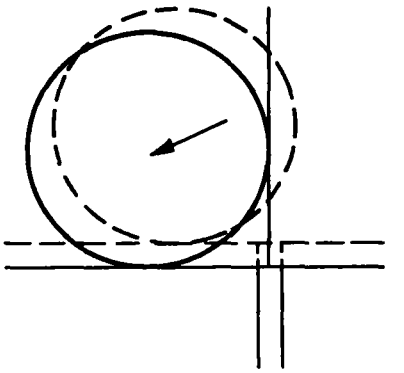
Figure 14–21. Determining the mean position of the sun.

b. Observations Without the Solar Circle. Special pointing techniques are required to measure angles to the center of the sun if the instrument is not equipped with the solar circle. It is necessary to measure the angle to one side of the sun with the telescope in the direct position and to the opposite side of the sun with the telescope in the reverse position. The mean value of these two angles is the mean angle to the center of the sun at the mean time of the observation (fig 14–21). The sides of the sun are referred to as the right and left limbs. When horizontal and vertical angles are required at the same time, it is necessary to place the right or left limb and the upper or lower limb of the sun tangent to the horizontal and vertical crosslines at the same instant. To make the observation, the instrument operator observes the sun in one of the four quadrants of the reticle pattern, and the double tangency is achieved with the telescope in the direct position and again in the diametrically opposite quadrant with the telescope in the reverse position. This technique of determining the center of the sun is called the quadrant method and can be used either when the sun is observed directly through a sun filter or when the image of the sun is projected onto a card held to the rear of the telescope eyepiece. Since the sun appears to be moving both in altitude and azimuth, it would seem necessary to track the sun with both the horizontal and vertical motions until the sun becomes tangent to both the horizontal and vertical crosslines. Actually, the sun is placed tangent to one of the crosslines and tracked in this position with the appropriate tangent screw until the apparent motion of the sun moves it into tangency with the other crossline. To place the image of the sun in the correct quadrant, the instrument operator first observes the apparent motion of the sun through the telescope or on the card. If the apparent motion is through the first and third quadrants, the image of the sun should be placed in the second and fourth quadrants for the observation (fig 14–22). If the apparent motion is through the second and fourth quadrants, the observations should be made in the first and third quadrants (fig 14–23). The quadrants selected for the observations should be those separated by the single vertical crossline rather than those separated by the double crossline.

c. Altitude Method. For sun observations by the altitude method, the initial pointing on the azi-

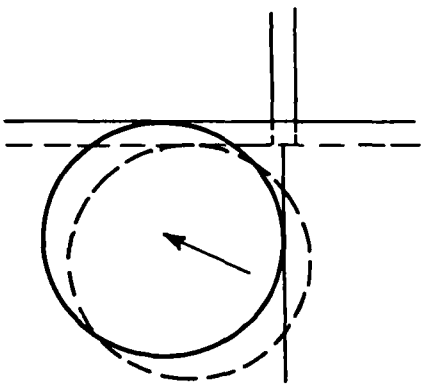


TELESCOPE REVERSE TRACK WITH HORIZONTAL MOTION

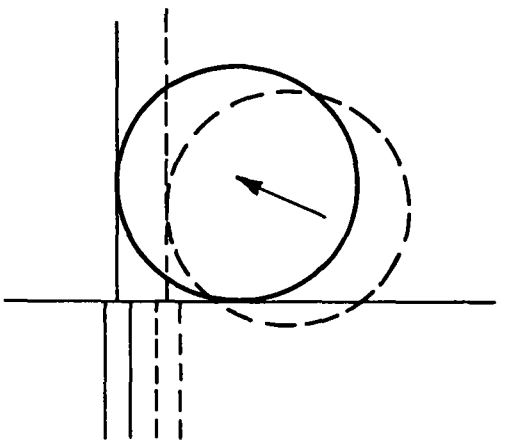


TELESCOPE DIRECT TRACK WITH VERTICAL MOTION

Figure 14-22. Observations when the apparent motion of the sun is through the first and third quadrants.



TELESCOPE REVERSE TRACK WITH VERTICAL MOTION



TELESCOPE DIRECT TRACK WITH HORIZONTAL MOTION

Figure 14-23. Observations when the apparent motion of the sun is through the second and fourth quadrants.

muth mark is made with the telescope in the direct position. The horizontal circle reading is recorded, the sun filter is placed on the eyepiece, and the telescope is pointed toward the sun. The telescope can readily be positioned on the sun by either sighting through the open telescope sights or by observing the shadow of the telescope on a flat surface held to the rear of the eyepiece and perpendicular to the telescope axis. With both the horizontal and vertical motions unclamped, the telescope is moved until the open sights are alined on the sun or until the shadow of the telescope forms a circle. The image of the sun will then be visible through the telescope. The motions of the instrument are clamped, the pointing is completed, and, at the instant the sun is centered in the solar circle or tangent to the crosslines, the instrument operator announces TIP, and the recorder notes and records the time, along with the horizontal and vertical circle readings. The telescope is reversed, a second pointing is made on the sun, and again the time and circle readings are recorded.

The instrument is then pointed to the azimuth mark, and the horizontal circle reading is again recorded to complete one position.

d. Hour-Angle Method. Sun observations for the hour-angle method require only the horizontal angle from the azimuth mark to the sun and the time of the observation. Observations with theodolites equipped with the solar circle can be made by centering the sun in the solar circle in the same manner as the altitude method or the procedures described below, which are applicable to all instruments, can be used. After the initial pointing on the azimuth mark, the telescope is pointed toward the sun, and the single vertical crossline is positioned just ahead of the leading edge of the sun so that the sun will move into tangency with the crossline near the center of the reticle. The telescope remains stationary, and, just before the sun becomes tangent to the crossline, the instrument operator announces READY and, at the instant of tangency, TIP. The recorder notes and records the exact time of tangency and the horizontal circle reading as announced by the instrument operator. The telescope is placed in the reverse position, and the same procedures are used to make a second pointing on the sun, except that the pointing is made on the trailing edge to proved pointings to opposite limbs of the sun. The instrument is then pointed to the azimuth mark, and the horizontal circle reading is again recorded to complete one position.

14–14. Time of Observation

a. The time at which pointings are made to a celestial body are recorded to the nearest second for all methods of astronomic observation. Accuracy requirements for time vary with the method and the body being observed, but recording to the nearest second allows detection of erratic data.

b. The altitude method used with a star requires time accurate to the nearest day; used with the sun, time must be accurate to the nearest 5 minutes. The Polaris tabular method requires time accurate to the nearest 1 minute. The hour-angle method used on Polaris requires time accurate to the nearest 10 seconds. The hour-angle method used with the sun or an east-west star requires time accurate to the nearest second. A reliable watch with a sweep second hand must be used for all observations, and it should be checked against a standard radio time signal before and after observation to determine any correction (para 14–35).

c. To obtain the accurate time of an observation, the instrument operator announces READY a few seconds before the star is at the intersection of the crossline or before the sun is tangent to the crosslines. He announces TIP and stops tracking at the exact instant the star is bisected or the sun is centered or at tangency. The recorder reads and records the time corresponding to the exact time that the instrument operator says TIP. The times corresponding to the direct reading and the reverse reading are used to determine the mean time of the observation.

14–15. Field Procedures

The 0.002 mil and the 0.2 mil theodolites are employed in the same manner to measure the horizontal and vertical angles to the sun or a star and to measure horizontal and vertical angles between two terrestrial stations. The angles are determined by taking the difference in circle readings between the two points. The procedures for measuring horizontal and vertical angles for astronomic observations are as follows:

a. Set up and level the instrument over the selected station in the prescribed manner.

b. With the telescope in the direct position, sight on the azimuth mark with the horizontal circle setting 0.150, ±0.100 mils (0.002 mil theodolite) or 1.0 mil (0.2 mil theodolite); read and record the circle reading.

c. Sight on the selected celestial body (para 14–12 or 14–13); read and record the time and the horizontal circle reading, level the split bubble, and read the vertical circle (if required).

d. Plunge the telescope to the reverse position and again sight on the sun. Read and record the time and the circle readings.

e. Sight again on the azimuth mark; read and record the horizontal circle reading. Determine the mean data.

14–16. Recording and Meaning Data

a. Altitude Method. Figure 8–13 shows data recorded in a field notebook for observations by the altitude method on an east-west star, using a 0.002-mil thoedolite. The format for recording field data and determining the mean angles is generally the same as for other angle measurements except for the spread between direct and reverse readings caused by the apparent motion of the celestial body. An additional column is included for recording the times of observations. The mean

time of observation is determined from the times recorded for the direct and the reverse pointings. The same format is used for observations with the 0.2-mil theodolite. The "remarks" must include the latitude, longitude, and description of the station, the temperature at the time of observation, the watch correction, if any, and the approximate azimuth to azimuth mark.

b. Hour-Angle and Polaris Tabular Methods. Figure 8–15 shows data recorded in a field notebook for observations by the hour-angle method of Polaris or the Polaris tabular method, using a 0.2-mil theodolite. The format differs from that for an altitude method observation in that no vertical angles are recorded and the temperature is omitted from the remarks. The same format is used for observations with the 0.002-mil theodolite. Sun observations are recorded in the same manner as star observations.

Section III. THE ARMY EPHEMERIS

14–17. Contents of the Army Ephemeris

The Army Ephemeris, which is a condensation of data found in the American Ephemeris and Nautical Almanac, is published as Technical Manual 6–300—current year. It is issued to all artillery units whose equipment permits astronomic observations. Data in the tables of the Army Ephemeris are required in computing direction from astronomic observations. The use of the tables is explained in paragraphs 14–18 through 14–30. Sample problems are based on data in TM 6–300–62.

14–18. Table 1b, Astronomic Refraction Corrected for Temperature (Mils)

a. Table 1b of the Army Ephemeris is used to determine the value of the refraction correction for temperature in mils. This correction is applied to vertical angles measured to either the sun or the stars. Refraction is the apparent displacement of a celestial body caused by the bending of light rays passing through layers of air of varying density. The celestial body appears higher than it really is; therefore, the sign of the correction is always minus.

b. The value of the refraction correction is determined by using as arguments the mean vertical angle (observed altitude) and the temperature at the time of observation. Arguments for the temperature increase in units of 10°, from —30° F to +130° F. Arguments for the observed altitude increase in units of 10 mils, from 0 mils through 1,200 mils. When the observed altitude and temperature are not tabulated in the table, enter the table with the values closest to those observed. For example, to determine the refraction correction for the mean vertical angle of 697 mils and a temperature of +93° F at the time of observation, use the following procedure: Examine the table. The nearest tabulated altitude is 700 mils, and the nearest temperature is +90° F. Enter the table at 700 mils and move right to the column for 90° F. Extract the refraction correction of —0.32 mil. Shoould the mean vertical angle fall exactly halfway between two tabulated altitudes, use the next higher tabulated altitude. Should the temperature fall exactly halfway between two tabulated temperatures, use the next lower tabulated temperature. For example, determine the refraction correction for a mean vertical angle of 745 mils and a temperature of +95° F. Since the mean vertical angle is exactly halfway between two tabulated altitudes (740 mils and 750 mils), select the higher value, 750 mils. And, since the temperature is halfway between two tabulated temperatures (+90° and +100°), select the lower, 90°. Extract the refraction correction of —0.29 mil.

14–19. Table 2, Sun, 1962 (For Zero Hours Greenwich Mean Time)

Table 2 is divided into three major parts—apparent declination (shown in both degrees and mils), equation of time, and sidereal time. Each of the major parts will be discussed separately. The first two columns are common to all three parts of table 2 and contain the Greenwich date and day of the week for the entire year.

a. Apparent Declination. The declination of a celestial body is the angular distance from the celestial equator measured along the hour circle of the body. Declination, which is given the positive sign when the body is north of the celestial equator and the negative sign when it is south, corresponds to latitude on earth. The function of the declination of the sun, which is required in both the hour-angle and altitude methods for determining azimuth by solar observation, is explained in more detail in paragraph 14–33. The declination of the sun is tabulated for zero hours Greenwich mean time (GMT) for each day of the year, and the daily change in declination is shown in the "Daily Change" column. The declination for a spe-

cific time is determined by using DA Form 6–11 for the computation, extracting the value of the daily change, to the nearest second, from the ephemeris. The algebraic signs of the declination and the daily change are critical and must be included. In computing the apparent declination in mils, the value should be determined to the nearest hundredth of a mil.

b. Equation of Time. The equation of time is the difference between the apparent solar time and the mean solar time. It is used to convert the mean solar time to the apparent solar time for use in the hour-angle method of determining azimuth from astronomic observations on the sun. The value to the nearest second is extracted from table 2. The daily change value is used to enter table 3.

c. Sidereal Time. The local sidereal time is the number of hours, minutes, and seconds that have elapsed since the vernal equinox last crossed the observer's meridian. The sidereal time in table 2 is Greenwich sidereal time, or the number of hours, minutes, and seconds that have elapsed since the vernal equinox last crossed the Greenwich meridian. Sidereal time is used when hour-angle observations have been made on stars and it is necessary to convert mean time into sidereal time. The sidereal time is extracted to the nearest second. Table 4 is used to determine the sidereal time.

14–20. Table 3, Equation of Time Graph

Whereas table 2 gives the equation of time for zero hours Greenwich mean time (GMT) for each day of the year and the daily change in the equation of time, table 3 serves as a graphic interpolation to find the daily change for a given time of day. The arguments used for table 3 are the daily change in the equation of time and the Greenwich mean time of observation. The daily change in the equation (eq) of time is taken from table 2, rounded off to the nearest second, and used as the argument to enter the equation of time graph. The Greenwich mean time of observation is the actual watch time with the time zone correction applied. This time is rounded off to the nearest 10 minutes and used as the argument to enter the bottom of the equation of time graph.

Example:

GMT of observation = $23^h41^m39^s$, 4 July 1962.
Determine Greenwich apparent time (GAT).

GAT = (GMT + equation of time for 0^h GMT + Partial day)
GMT = $23^h41^m39^s$
Equation of time for 0^h GMT = -4^m08^s
Daily change (change for 23^h40^m) = -11^s
GAT = $23^h37^m20^s$

14–21. Table 4, Correction to Greenwich Mean Time

Table 4, a tabulation of the time difference between mean and sidereal time for a 24-hour period, is used with the sidereal time in table 2. When an astronomical observation has been made on a star, one of the computational requirements is to convert GMT into Greenwich sidereal time (GST). GST is determined by adding the value of sidereal time at zero hours GMT from table 2 and the correction from table 4 to the GMT of the observation.

Example: The GMT observation is $4^h12^m32^s$, 6 July 1962. Determine the GST.

Solution: Sidereal time for 0^h GMT = $18^h53^m59^s$. Round off GMT to hours and minutes and use as arguments to enter table 4 (correction for GMT interval). Across the top of table 4, select the correct number of hours; i.e., 4^h. In the first column of table 4, find the correct number of minutes (12^m32^s = 13^m); i.e., 13^m. At the intersection of the column and line, extract the correction to the nearest second which is $0^m41.6^s$ and rounded off to 0^m42^s.

Now: $4^h12^m32^s$ (GMT)
$+18^h53^m59^s$ (GST for 0 hour GMT)
$+\ 0^m42^s$ (Correction for 4^h13^m)
$23^h07^m13^s$ = GST for GMT $4^h12^m32^s$, 6 July 1962.

14–22. Table 5a, Conversion of Time into ARC

In using the hour-angle method to determine azimuth, it is necessary to express the time in units of arc. Table 5a is used for this conversion. It is divided into three sections—the arc equivalents of hours, minutes, and seconds of time.

Example: Convert $8^h08^m59^s$ into arc (mils).

Solution: From table 5a:

8^h	=	2,133.33 mils
08^m	=	35.56 mils
59^s	=	4.37 mils
		2,173.26 mils

14–23. Table 5b, Conversion of Arc to Time (TM 6–300–67)

Table 5b, which appears in the 1967 and subsequent Army Ephemerises and as appendix F to this manual, converts arc in degrees to units of time. This conversion is necessary for determining local sidereal time for the Polaris tabular method. Longitude is converted to the nearest second in time but is used to the nearest minute.

Example: Convert 98°24′18″ to units of time.

Solution: From table 5b:

98°	=	6^h32^m
24′	=	1^m36^s
18″	=	1^s
98°24′18″	=	$6^h33^m37^s$, or 6^h34^m

14–24. Table 6, Convergence

Table 6 contains the value of function XV (a variable function based on the latitude of the station), which is required in the computation of convergence. Convergence is the difference between true north and grid north. The direction determined by astronomic observation is true direction and must be converted to grid direction for use in artillery survey. Convergence is computed by using DA Form 6–20. At this time, however, the point of interest is the determination of function XV and not the computation of convergence. The argument used in table 6 is the UTM grid northing coordinates of the station. This coordinate should be rounded off to the nearest 100 meters. The table includes the northing coordinates and function XV for each 10,000 units of northing (every 1,000 for northings below 10,000). It is necessary to interpolate to find function XV for a northing coordinate to the nearest 100 meters.

Example: Northing coordinate is 571827.49. Determine function XV.

Solution: Northing coordinate rounded off is 571800.00

$$10{,}000 \left\{ \begin{array}{l} \\ \\ \end{array} \right. \quad 1800 \left\{ \begin{array}{l} 570{,}000 = 2919.9 \\ \\ 571{,}800 = \ ? \\ 580{,}000 = 2971.4 \end{array} \right\} \text{X} \left. \begin{array}{l} \\ \\ \end{array} \right\} 51.5$$

$$\frac{x}{1800} = \frac{51.5}{10{,}000} \qquad 10{,}000\ x = 92{,}700 \qquad x = 9.3$$

$2919.9 + 9.3 = 2929.2$ = function XV.

Note. For computation on DA Form 620, the log of 2929.2 is obtained from the logarithmic tables in TM 6–230 or TM 6–231. (The five-place logs in table 6 are not used.)

14–25. Table 7, Second Term in Convergence (UTM Grid)

Table 7 contains a correction known as the second term in convergence. The correction from this table is used in the computation on DA Form 6–20. The table is divided into the following two parts:

a. The first part is for northings from 6,000,000 to 9,000,000. Enter the table with the northing to the nearest 50,000 meters and the easting to the nearest 5,000 meters. Where the lines representing the northing and easting of the station meet, read the value of the second term in convergence marked between the lines. Do not interpolate for values less than 1 second. If the station is in the Southern Hemisphere, subtract the northing from 10,000,000 before entering the table.

b. The second part of table 7 is the northings from 0 to 6,000,000. Enter the table with the northing of the station to the nearest 100,000 meters and the easting to the nearest 5,000 meters.

Example: Grid coordinate of station: (751846.92 — 4870491.70). Enter the northing at 4,900 (northing to nearest 100,000). Enter the easting at 750 (easting to nearest 5,000). Extract the second term in convergence at 8", or 0.04 mil, using the conversion table in table 7.

14–26. Table 8b, Second Term in Convergence (Geographic)

Table 8b is also used in the computation of convergence, using geographic coordinates in mils. The arguments are the latitude of the station to the nearest 10 mils and the difference between the longitude of the station and the longitude of the central meridian of the grid zone to the nearest 1.25 mils. The longitude of the central meridian of the grid zone can be found in the table on the back of DA Form 6–20.

Example: The latitude of the station is 720 mils; the longitude of the station is 1,720 mils. Determine the second term in convergence.

Solution: Enter the graph at the left of the 720-mil line and at the bottom along the 40-mil line (the difference between 1,760 mils (central meridian) and the longitude of the station). The second term in convergence is 0.01 mil.

14–27. Table 9, Alphabetical Star List

Table 9 contains an alphabetical list of 73 stars, the constellation in which each star is found, the number of each star, and the magnitude of each star. This table is used primarily to furnish the numbers of the stars in order to determine data on the stars from table 10. The constellation name and the star's magnitude aid in identifying the star.

Example: The star is Enif. Determine its constellation, number, and magnitude.

Solution: Pegasus, 70, 2.5.

14–28. Table 10b, Apparent Places of Stars (Mils)

Table 10b contains the right ascension and declination in mils for the stars listed in table 9 except for Polaris. Right ascension and declination are given for the first day of each month, and values for other dates are interpolated for in the following manner:

a. Determine the difference for both the right ascension and the declination (in seconds and mils, respectively) from the first of the month to the first of the following month.

b. Divide the number of days past the first of the month by 30 days (standard month) and mul-

tiply this value by the differences determined in *a* above to obtain the change in the right ascension and in the declination from the first of the month.

c. Apply the changes determined in *b* above to the right ascension and declination at the first day of the month to determine the right ascension and declination for the day.

Example: Determine the right ascension and declination of the star Alpheratz (No. 1) on 22 April 1962.

Solution: Right ascension:

1 April 1962 = $0^h06^m23.9^s$
1 May 1962 = $0^h06^m24.4^s$
Difference 0.5^s
$22/30 \times 0.5 = 0.4$
$23.9^s + 0.4^s = 24.3^s$
Expressed to the nearest second, 24^s.
Right ascension for 22 April 1962 = $0^h06^m24^s$.

Declination:

1 April 1962 + 513.39mils
1 May 1962 + 513.38mils
Difference 0.01mils
Declination for 22 April 1962= 513.38 mils

14–29. Table 11, Apparent Places of Polaris

Table 11 contains the declination (degrees and mils) and the right ascension of Polaris. The values listed are for 1200 hours GMT on 0, 10th, 20th, and 30th days of the month. To determine the declination or the right ascension of Polaris for a given day, interpolate between the tabulated values. Data for the 31st day of a month are shown as the 0 day of the following month.

Example: Determine the declination and right ascension of Polaris on 13 November 1962. Declination in mils is determined and used in the computations to the nearest one-hundredth of a mil.

Solution:

	Declination	*Right Ascension*
10 November 1962	+1583.85	$1^h59^m10^s$
20 November 1962	+1583.87	$1^h59^m06^s$
	0.02	04^s

$3/10 \times 0.02 = 0.006$ $3/10 \times 04^s = .2^s$
$1583.85 + 0.006 = 1583.856$ $10 - 1.2 = 08.8^s$
Declination = +1583.86 mils Right ascension = $1^h59^m09^s$

14–30. Table 12, To Determine Latitude and Azimuth From Polaris

Field artillery surveyors use table 12 only to determine azimuth by the Polaris tabular method.

a. Extraction of b_0. The argument used for extracting b_0 is local sidereal time (para 14–50*a*(1)). The hours of local sidereal time (LST) are listed in columns across the page, and the minutes of LST are listed downward within the hour columns.

Example: Find b_0 for LST 8^h34^m.

Solution: In the column marked "8^h" and the subcolumn marked "b_0", move down the left side of the page until the row designated at 33 minutes is located. Interpolating between 33 and 36 minutes, read 53.8 minutes of arc.

b. Extraction of b_1. The arguments are the same column used to find b_0 and the observer's latitude.

Example: Find b_1 for LST 8^h34^m at latitude 34°40'.

Solution: Using the 8^h column, move down the left side of the page to the row marked "30°". Interpolating between 30° and 40°, read −0.1 minute of arc.

c. Extraction of b_2. This value is found in the same manner as b_1, except that the date of observation is used as an argument instead of latitude.

Section IV. AZIMUTH BY THE ALTITUDE METHOD

14–31. The Altitude Method

a. General. The altitude method may be used to determine azimuth from the sun or from the stars. This method requires the solution of the celestial triangle (fig 14–24) by using, as known data, the three sides of the triangle (polar distance, colatitude, and coaltitude). In the altitude method, the time is required only to determine the declination of the body. When the sun is observed, the time should be accurate to within 5 minutes. For stars, only the date is required. Since time is not critical in the altitude method of observation, this method is used most frequently by artillery surveyors.

b. Position of Celestial Bodies for Observation. Stars for altitude observation should be selected by using the star rate templates and the star finder (section V). When the sun is observed, it should be within 530 mils of the observer's prime vertical, which is the arc on the celestial sphere which passes through points due east and west of the observer and through his zenith. The sun must not be within 2 hours of the observer's meridian. For the best results, it should be above 175 mils in altitude. Unless an elbow telescope or the card method is used, the sun must be below 800 mils in altitude.

14–32. Determination of PZS Triangle Sides

The formula for solving the triangle has been arranged in a manner that requires only the computation of the polar distance side. The other sides are stated in the formula in terms of latitude and

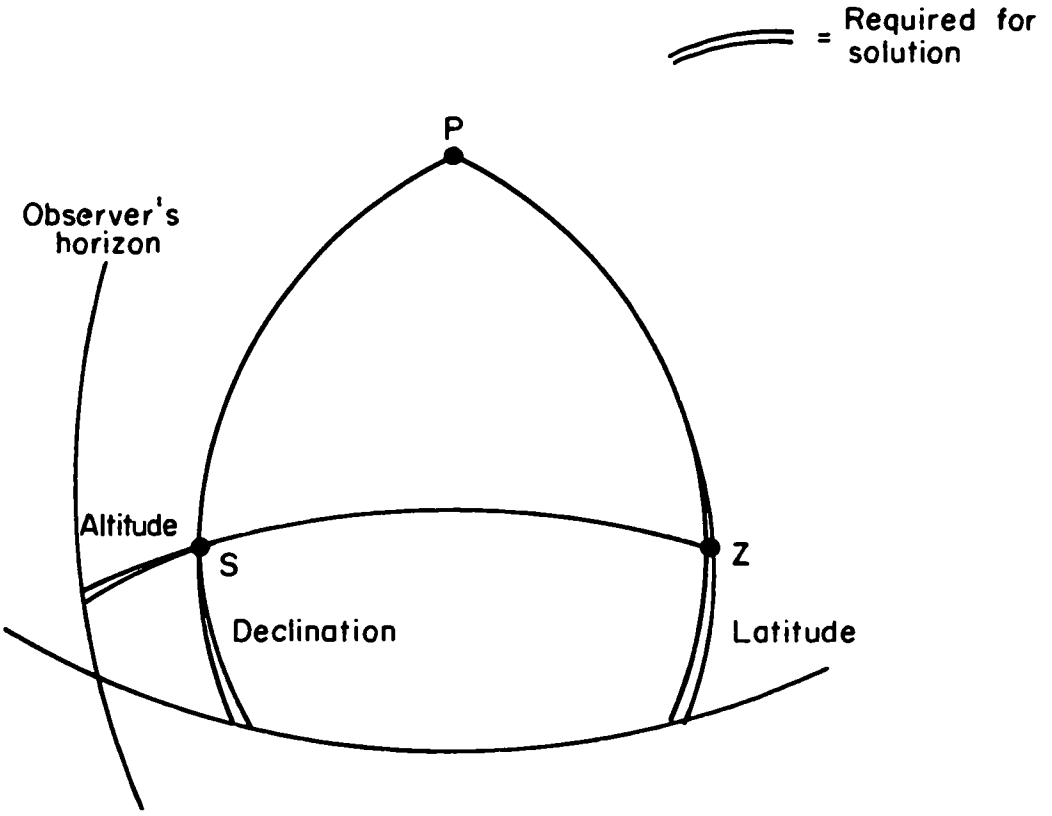


Figure 14–24. Solution of PZS triangle—altitude method.

altitude, thus eliminating the need for computing colatitude and coaltitude.

a. Polar Distance. The side of the celestial triangle from the pole to the body is determined from the declination of the body. The declination, extracted from the Army Ephemeris, is subtracted from 1600‰ when positive and added to 1600‰ when negative to obtain polar distance.

b. Colatitude. The side of the triangle from the pole to the zenith, colatitude, is determined by subtracting the latitude of the observer from 90°. The latitude of the observer's station may be determined from a map with a scale of 1:50,000 or larger. If the geographic coordinates of the station are tabulated in a trig list, the latitude may be extracted and used, thus eliminating the need for a map.

c. Coaltitude. The side of the triangle from the celestial body to the zenith (coaltitude) is determined by subtracting from 90° the corrected observed vertical angle to the body. The vertical angle to the sun must be corrected for parallax and refraction. Vertical angles to stars are corrected for refraction only.

(1) *Parallax.* The word "parallax" is defined as the apparent displacement of a celestial body depending on a change in the position of the observer. An observed altitude of the sun is corrected for parallax; that is, for the error introduced by the fact that the observer is on the surface of the earth and not at the center (fig 14–25). This difference is negligible on vertical angles to the stars because they are so far from the earth.

(The nearest star is 26×10^{12} miles from earth, whereas the sun is only 93×10^{6} miles away.) The parallax of the sun varies from +9″ when the sun is on the horizon to 0″ when the altitude of the sun is 90°. For field artillery surveys, the constant for the parallax of the sun is considered as +7″, or +0.04 mil.

(2) *Refraction.* The refraction (fig 14–26) of a celestial body is the apparent displacement of the body caused by the bending of the rays of light passing through layers of air of varying density. A ray which enters the atmosphere and barely grazes the earth's surface will be compelled to pass through the air at a larger angle of incidence (i.e., the angle formed by the line of a falling ray and a perpendicular arising from the point of entry into the atmosphere) than a ray that is more perpendicular to it; consequently, the refrac-

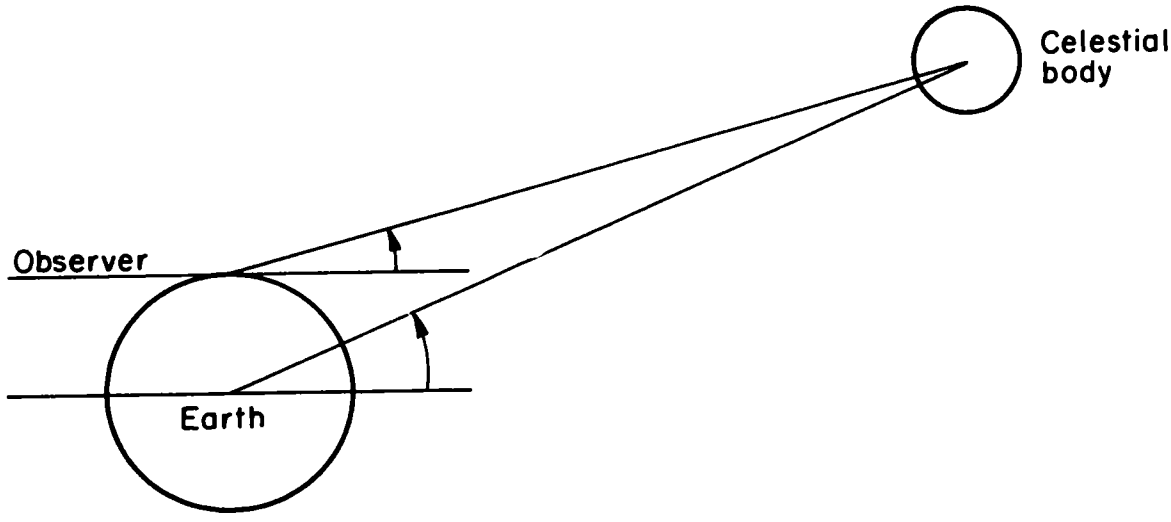


Figure 14–25. Parallax correction.

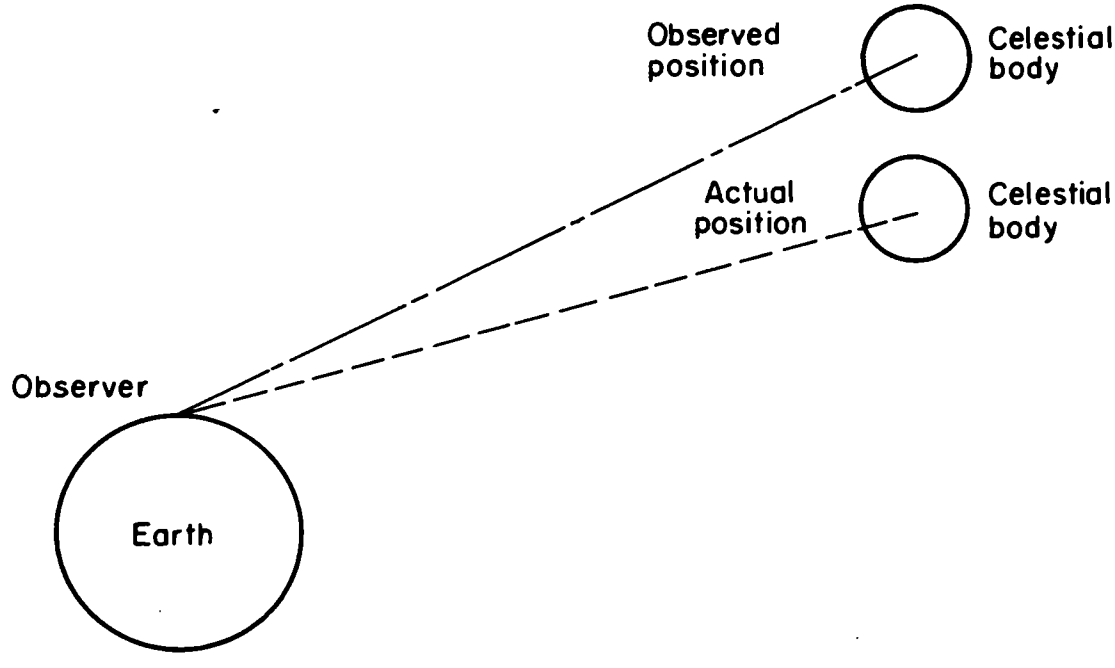


Figure 14–26. Refraction correction.

tion is greater. On the other hand, a ray entering the atmosphere exactly perpendicular to the earth is not affected at all. The refraction varies according to the altitude of the source of light above the horizon. At a temperature of +70°, refraction of a body on the horizon is 10.26 mils; refraction of a body at the observer's zenith is 0 mils. Refraction increases with an increase in the barometric pressure and a decrease in temperature, and vice versa. The refraction correction is given in the Army Ephemeris and is applied to observed altitudes of the sun and stars. The sign of the refraction correction is always minus.

14–33. Formula for Altitude Method Solution of the Astronomic Triangle

Several formulas can be derived for the solution of a spherical triangle whose three sides are known. The formula selected for use in artillery survey, because of its simplicity and adaptability to a log-

arithmic solution, is

$$\tfrac{1}{2}A = \sqrt{\frac{\cos s \cos (s-p)}{\cos \text{ lat} \cos h}}$$

where A = astronomic azimuth of the body measured east or west of the meridian.

s = ½ the sum of polar distance, latitude, and true altitude.

p = polar distance.

lat = latitude of station.

h = true altitude of the celestial body.

In solving for azimuth, as in other survey problems, a standard DA form has been designated to facilitate the necessary computations. DA Form 6–11 has been designed to solve for azimuth by the altitude method formula.

14–34. DA Form 6–11

DA Form 6–11 (Computation—Astronomic Azimuth by Altitude Method, Sun or Star) (fig 14–27 and 14–28) is divided into eight general parts—marginal data, lines 1–6, lines 7–11, lines 12–22, lines 23–34, and lines 35–37 on the front and the auxiliary computations and the guide on the back.

a. Marginal Data. Blocks are provided on the front of the form for recording the latitude and longitude of the station, temperature, approximate azimuth to the azimuth mark, local, date, azimuth mark, station, sketch, computer, checker, sheet number, notebook reference, area, and date.

b. Lines 1 through 6. On lines 1 through 6, enteries are made for the computation of Greenwich mean time and the Greenwich date.

c. Lines 7 through 11. On lines 7 through 11, the observed vertical angle to the sun is corrected for parallax and refraction.

d. Lines 12 through 22. On lines 12 through 22, the values in the formula of s, p, and (s–p) are determined.

e. Lines 23 through 34. On lines 23 through 34, the formula is solved by using logarithms.

f. Lines 35 through 37. On lines 35 through 37, the azimuth of the sun is determined, and the measured horizontal angle is applied to determine the astronomic azimuth to the mark.

g. Auxiliary Computations. On the back of the form, the auxiliary computations are made for the declination of the sun at the time of observation. The results of these computations are entered on line 12 on the front of the form.

h. Guide. The guide on the right of the back of the form includes the field data, limitations, results, and formula.

14–35. Fieldwork

The fieldwork necessary for azimuth determination by the altitude method includes measuring the horizontal and vertical angles and recording the time of the observation and the temperature. The temperature should be recorded at the beginning of the observation and again when the observation has been completed. The mean of the temperatures is used in the computation. The watch used in the observation should be checked with radio time signals to determine the watch correction. The time signals broadcast by WWV, Fort Collins, Colorado, can be picked up on 2.5, 5, 10, 15, 20 and 25 megahertz 11 minutes before the hour continuing until 45 minutes past the hour. The signal is a 1000 cycle pulse of 0.005 second duration at each second except the 59th and a double signal on the minute. The exact second is referenced at the beginning of the pulse. GMT voice broadcast is prior to each 5 minute interval. The minute hand of the watch to be used should be set exactly by the time signal. No attempt should be made to set the second hand. The watch correction is determined by noting the position of the second hand at the time of the tone. Then the number of seconds at which the second hand was positioned before or after the 0-second mark, is recorded, along with the proper sign, as the watch correction. The procedure for time signals elsewhere may vary slightly from the above.

14–36. Effects of Errors

Particular attention should be paid to securing the best available data. Roughly, an error of 1 minute in either latitude, declination, or altitude may cause a corresponding error of more than 0.50 mil in azimuth. Time is less important in a sun observation because an error of 5 minutes cannot change the azimuth more than 0.03 mil.

14–37. Determination of Final Azimuth

a. Technique for Determining Azimuth for Fifth-Order Survey. To determine azimuth for a fifth-order survey using the 0.2-mil theodolite, observe and compute at least three sets of observations (each set, one position). Mean the azimuths and reject any set which varies from the mean by more than 0.3 mil. At least two sets must be meaned to determine final azimuth. The consid-

COMPUTATION - ASTRONOMIC AZIMUTH BY ALTITUDE METHOD, SUN OR STAR (FM 6-2)

TABLE NOS. REFER TO TM 6-300-19 62

SUN OR STAR NAME AND NO. (Table 9): SUN

LATITUDE OF STATION	LONGITUDE OF STATION	APRX AZ TO AZ MK	LOCAL DATE	AZIMUTH MARK	STATION
34° 39' 48" N	98° 24' 18" W	4270	16 Apr 62	ASM#46	OSB

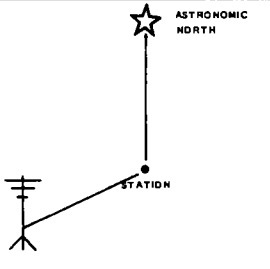
TEMPERATURE +50 °F

DATE 4-16-69 | AREA Comanche County | NOTEBOOK REFERENCE B-4

		SET NO. 1	SET NO.	SET NO.
1	MEAN WATCH TIME OF OBSERVATION	8h 47m 00s		
2	WATCH CORRECTION (SLOW +, FAST −)			
3	ALGEBRAIC SUM (1) AND (2)	− 8 47 00		
4	TIME ZONE CORRECTION (W LONG +, E LONG −)	+ 6		
5	ALGEBRAIC SUM (3) AND (4)	+ 14 47 00		
	GREENWICH DATE * 16 Apr 19 62	24 00 00	24 00 00	24 00 00
6	GREENWICH MEAN TIME (GMT)*	14 47 00		
7	OBSERVED ALTITUDE OF SUN OR STAR	5 93.80		
8	PARALLAX (Sun only) +0.04 MILS	+.04		
9	FOR SUN: (7) + (8) FOR STAR: REPEAT (7)	5 93.84		
10	REFRACTION (Table I, Mils)	−.44		
11	(9) − (10) TRUE ALTITUDE (h)	5 93.40		
12	APPARENT DECLINATION. (Sun, (14) of aux comp on rev star on date in (6)(Table 10-Mils.)	+ 1 79.39		
13	1600.00 m	+ 16 00.00		
14	REPEAT (12) WITH SIGN REVERSED	− 1 79.39		
15	ALGEBRAIC SUM (13) AND (14)	+ 14 20.61		
16	REPEAT (11)	+ 5 93.40		
17	(15) + (16)	+ 20 14.01		
18	LATITUDE (17) of conversion to mils comp on reverse) (NORTH +, SOUTH −)	+ 6 16.24		
19	ALGEBRAIC SUM (17) AND (18)	26 30.25		
20	1/2 DF (19)	13 15.12		
21	REPEAT (15)	14 20.61		
22	SUBTRACT SMALLER, (20) OR (21), FROM LARGER, (21) OR (20). SIGN ALWAYS PLUS	13 15.12		
		+ 1 05.49		

		SET NO. 1	SET NO.	SET NO.
23	LOG COS (18)	9.915 151		
24	LOG CO3 (11)	9.921 714		
25	(23) + (24)	9.836 865		
26	LOG COS (20)	9.441 015		
27	LOG CO3 (22)	9.997 666		
28	(26) + (27)	9.438 681		
29	REPEAT (25)	9.836 865		
30	(28) − (29)	9.601 816		
31	(30) + 10.000 0000	19.601 816		
32	1/2 DF (31)	9 800.908		
33	ANGLE HAVING LOG CO3 (32)	9 02.8		
34	2 × (33)	18 05.6		
35	WHEN SUN (alter) IS EAST AND (34) IS LESS THAN (36) GREATER THAN (36) (135) IS (34) + 6400 REPEAT (34)	64 00.0		
	WHEN SUN (alter) IS WEST AND 6400 − (34) IS LESS THAN (36) GREATER THAN (36) (35) IS 12800 − (34) / 6400 − (34)	18 05.6		
		82 05.6		
36	MEAN HORIZONTAL ANGLE	38 86.6		
37	(35) − (36) = ASTRONOMIC AZIMUTH TO MARK	43 19.0		

SKETCH



* IF (5) IS: (+) AND LESS THAN 24 HRS; (+) AND MORE THAN 24 HRS; (−). GREENWICH DATE (6) IS: LOCAL DATE; LOCAL DATE + 1 DAY; LOCAL DATE − 1 DAY. AND GMT (6) IS: SAME AS (5); (5) − 24 HRS; 24 HRS − (5)

COMPUTER: KRUCK

CHECKER: BAKER

SHEET 1 OF 1 SHEETS

DA FORM 1 JUN 67 6-11 REPLACES EDITION OF 1 DEC 66, WHICH MAY BE USED.

Figure 14–27. Completed DA Form 6–11 (front).

AUXILIARY COMPUTATION FOR APPARENT DECLINATION OF SUN AT GREENWICH DATE AND GMT

		SET NO. 1	SET NO.	SET NO.	
1	GREENWICH DATE (6) of computation)	16 Apr 62			1
2	GMT (Hours and minutes in (6) of computation)	HRS 14 MIN 47	HRS MIN	HRS MIN	2
		X60	X60	X60	
3	NUMBERS OF HOURS IN (2) × 60	840			3
4	NUMBER OF MINUTES IN (2)	47			4
5	(3) + (4)	887			5
6	DAILY CHANGE IN DECLINATION (Table 2)	± 6 32	±	±	6
7	LOG OF (5)	2 947 924			7
8	LOG OF (6)	0 800 717			8
9	LOG OF CONSTANT	6 841 6375	6 841 6375	6 841 6375	9
10	(7) + (8) + (9)	0 590 279			10
11	NO. HAVING LOG (10) MILS OF CHANGE	3 89			11
12	APPARENT DECLINATION AT 0^h ON GREENWICH DATE (Table 2)	± 1 75 50	±	±	12
13	(11) CONVERTED TO MINUTES AND SECONDS OR (11) IN MILS ((Use sign of (6))	± 3 89	±	±	13
14	ALGEBRAIC SUM (12) AND (13) ENTER IN (12) ON FRONT	± 1 79 39	±	±	14

CONVERSION TO MILS COMPUTATION

(For Fifth Order, use Table IIIb, TM 6-230 - For Fourth Order, use Table IIIa, TM 6-231)

1	LONGITUDE (From front of form)	98 ° 24 ' 18 "	10	LATITUDE (From front of form)	34 ° 39 ' 48 "
2	✓ IN HUNDREDS OF DEGREES OF (1)		11	✓ IN TENS OF DEGREES OF (10)	5 33 33
3	✓ IN TENS OF DEGREES OF (1)	16 00 00	12	✓ IN UNITS OF DEGREES OF (10)	71 11
4	✓ IN UNITS OF DEGREES OF (1)	1 42 22	13	✓ IN TENS OF MINUTES OF (10)	8 39
5	✓ IN TENS OF MINUTES OF (1)	5 93	14	✓ IN UNITS OF MINUTES OF (10)	2 67
6	✓ IN UNITS OF MINUTES OF (1)	1 19	15	✓ IN TENS OF SECONDS OF (10)	0 20
7	✓ IN TENS OF SECONDS OF (1)	0 05	16	✓ IN UNITS OF SECONDS OF (10)	0 04
8	✓ IN UNITS OF SECONDS OF (1)	0 04	17	SUM OF (11) THROUGH (16) (Enter in (18) on front and on DA Form 6-20)	6 16 24
9	SUM OF (2) THROUGH (8) (Enter on DA Form 6-20)	17 49 43			

GIVEN:
Time zone of area of operatioo.

FIELD DATA:
Latitude and longitude of atation.
Approximate azimuth to azimuth mark and to sun or stsr *(sketch)*.
Sun or name(s) and number(s) of selected star(s).
Local date of obaervation.
Temperature st time of observation.
Mean watch time of obaervation and wstch correction.
Horizontal clockwise angle from szimuth msrk to sun.
Observed altitude of *(vertical angls to)* sun or star.

GUIDE:
Enter observed field dats in block marked.
Lines *(7)* through *(22)* of computation sre computed usiog hundredth-mil values.
Linea *(6)* through *(14)* of AUXILIARY COMPUTATION sre computed using hundredth-mil values.
Linea *(2)* through *(9)* and *(11)* through *(17)* of CONVERSION TO MILS COMPUTATION are computed using hundredth-mil valuea.
Lines *(23)* through *(37)* of computstion are computed using tenth-mil values.
Value ln *(37)* should be about equsl to approximste szimuth to azimuth msrk.
Continue computations using DA Form 6-20 to obtsin the UTM grid azimuth.

LIMITATIONS:
This form should not be used when accurscies greater than fourth-order are required.
The altitude method should not be used when the sun ia --
a. Less than 20 degrees or more than 60 degreea above horizoo.
b. More than 30 degrees from a 90-degree or 270-degree azimuth *(east-west line)*.
For fsvorsble position of star aee FM 6-2.

RESULTS:
A value of sstronomic azimuth for each set of obaervations.

FORMULA:

$$\text{Cos } 1/2\ A = \sqrt{\frac{\text{Cos s Cos (s - p)}}{\text{Cos Lat Cos h}}}$$

A = astronomic szimuth of sun or star messured east or west of meridian.

s = 1/2 sum of polar distance, latitude, and true altitude.

p = polar distance of celestial body.

Lat= lstitude of station.

h = true altitude of celestial body.

Figure 14–28. Completed DA Form 6–11 (back).

ered accuracy of fifth-order astronomic observation is ±0.3 mil.

b. Technique for Determining Azimuth for Fourth-Order Survey. To determine azimuths for a fourth-order survey using the 0.002-mil theodolite, observe and compute at least three sets of observations (each set, one position). Mean the three azimuths and reject any azimuth which is more than 0.15 mil from the mean. At least two azimuths must be meaned to determine the final azimuth. The considered accuracy of fourth-order astronomic observation is ±0.15 mil.

14–38. Example of Computing Azimuth by the Altitude Method (Sun)

a. Given Data.

(1) Station: OS–B.

(2) Azimuth mark: ASM #46

(3) Local date: 16 April 1962.

(4) Celestial body observed: Sun.

(5) Time zone correction: +6 hours.

(6) Latitude: 34°39′4″N.
Longitude: 98°24′18″W.
Grid coordinates: (554518 – 3835674).

(7) Approximate temperature: +50°F.

(8) Watch correction: None.

(9) Approximate azimuth to the azimuth mark: 4,270 mils.

(10) Mean data from field notebook:
Watch time: $8^h47^m00^s$
Horizontal angle: 3,886.6 mils
Vertical angle: 593.8 mils

b. Solution. See figures 14–27 and 14–28.

Section V. AZIMUTH BY THE HOUR-ANGLE METHOD (SUN)

14–39. The Hour-Angle Method

a. General. In the hour-angle method of determining azimuth (by using observations on the sun), two sides of the PZS triangle (fig 14–29), the polar distance and colatitude, and one angle, the hour angle, are used to solve for the azimuth angle. The two sides are determined as in the altitude method; that is the polar distance is determined from the declination of the body, and the colatitude is determined from the latitude of the observer. The computation of the hour angle requires the use of several references on the celestial sphere. This computation is based on the time of the observation. The problem of determining azimuth consists of measuring the horizontal angle at

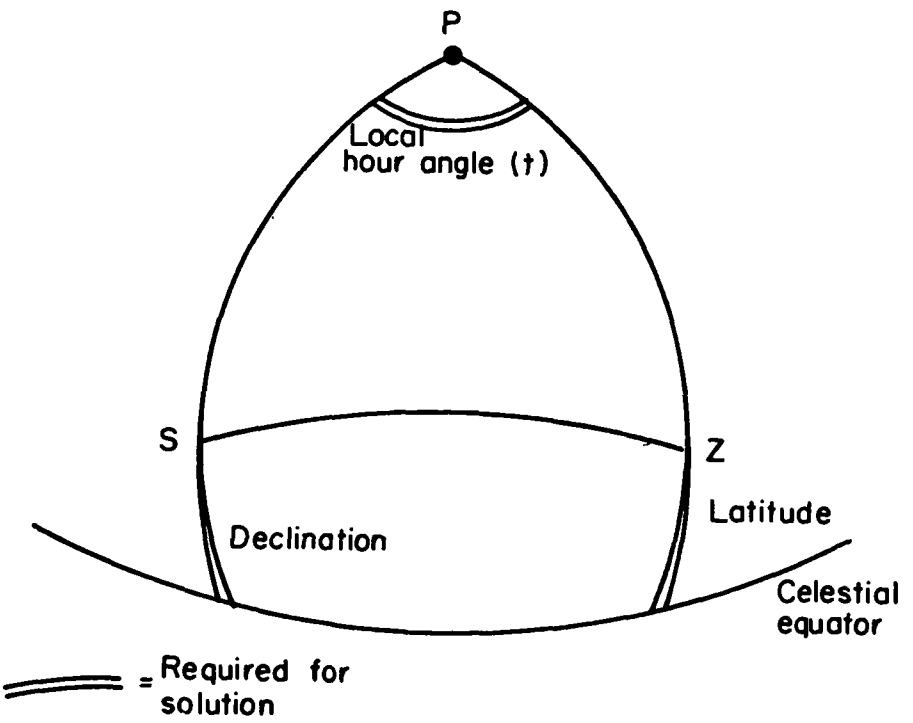


Figure 14–29. Solving the PZS triangle by the hour-angle method.

the observer's station between the mark and the sun, the azimuth of which can be computed. The simple operation of subtracting this horizontal angle from the computed azimuth of the sun gives the desired azimuth of the mark. The final azimuth is determined as described in paragraph 14–37.

b. Position of the Sun for Observation. For observations by the hour-angle method, the sun must not be within 1 hour of the observer's meridian; for best results, it should be above 175 mils in altitude. Unless an elbow telescope or the card method is used, the sun must be below 800 mils in altitude.

14–40. Determination of Local Hour Angle

For the hour-angle solution, the element of the PZS triangle that is observed is the local hour angle. This hour angle is determined by using the time of the observation. In general terms, the local hour angle is determined by converting the local mean time (watch time) to Greenwich mean time, to Greenwich apparent time, to Greenwich hour angle, and finally to local hour angle. Specifically, these steps can be outlined as follows:

Local mean time
+ time zone correction
= Greenwich mean time
± equation of time for 0^h
± daily change
= Greenwich apparent time
± 12 hours
= Greenwich hour angle
± longitude
= local hour angle.

a. Determination of Greenwich Mean Time. The watch time of the observation is referred to as local mean time. This watch time is standard time for the area of operation. By applying the time zone correction (number of 15° belts of longitude between the station and the Greenwich meridian), the Greenwich mean time is obtained.

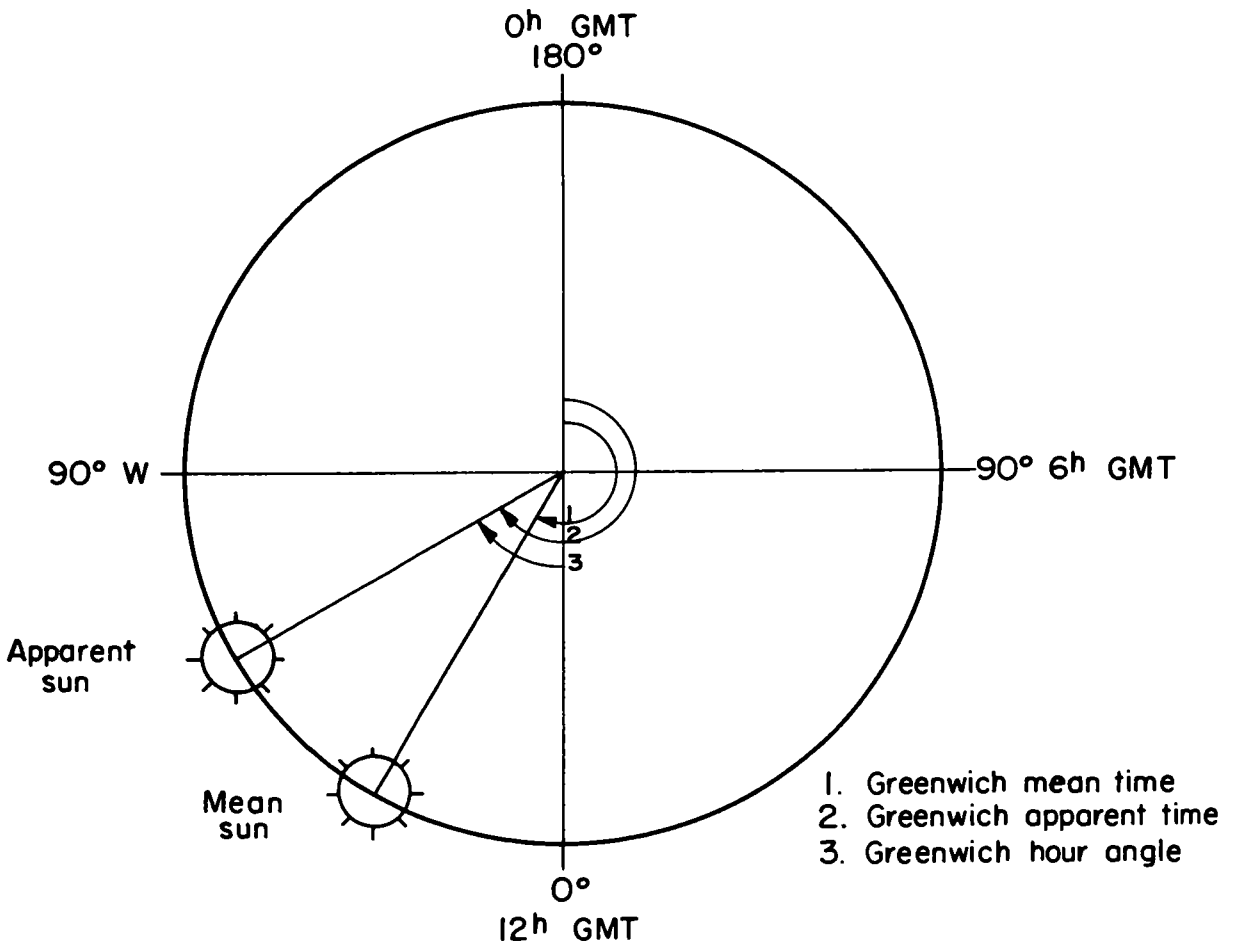


Figure 14–30. Computation of hour angle from time.

COMPUTATION - ASTRONOMIC AZIMUTH BY HOUR - ANGLE METHOD, SUN — TABLE NRS REFER TO TM 6-300-1962 — **SUN**

LATITUDE OF STATION	34 35 25 N	LONGITUDE OF STATION	98 22 24 W	APRX AZ TO AZ MK	169°0	LOCAL DATE	23 July 62
AZIMUTH MARK	TS 1	STATION	BOWL	DATE	23-7-62		

		SET HR 1	SET HR	SET HR
1	MEAN WATCH TIME OF OBSERVATION	9 47 44		
2	WATCH CORRECTION (SLOW +, FAST −)	− 12		
3	ALGEBRAIC SUM (1) AND (2)	− 9 47 56		
4	TIME ZONE CORRECTION (W LONG +, E LONG −)	+ 6		
5	ALGEBRAIC SUM (2) AND (4)	+ 15 47 56		
	GREENWICH DATE * 23 JULY 1962	24 00 00	24 00 00	24 00 00
6	GREENWICH MEAN TIME (GMT) *	15 47 56		
7	EQUATION OF TIME AT 0h ON GREENWICH DATE (TABLE 2)	+ 6 21		
8	ALGEBRAIC SUM (6) AND (7)	+ 15 41 35		
9	EQUATION OF TIME AT GMT (TABLE 2)	− 01		
10	ALGEBRAIC SUM (8) AND (9)	+ 15 41 34		
11	IF (10) IS: (+) AND LESS THAN 12h → (11) IS (10) + 12h; (+) AND MORE THAN 12h → (10) − 12h; (−) → ALGEBRAIC SUM (10) AND 12h	12 00 00 / + 3 41 34	12 00 00	12 00 00
12	(11) CONVERTED TO ARC [(5) OF CONV COMP ON REVERSE]	+ 9 84 74		
13	LONGITUDE [(9) OF CONVERSION TO MILS COMP ON REVERSE IF USING MILS] (EAST +, WEST −)	− 17 48 86		
14	ALGEBRAIC SUM (12) AND (13)	− 7 64 12		
15	IF (14) IS: (−) → 0° TO +180°: REPEAT (14); +180° TO 360°: 360° − (14), SIGN (−); MORE THAN 360°: (14) − 360°, SIGN (+)	− 7 64 12		
16	1/2 OF (15)	− 3 82 06		
17	LATITUDE [(17) OF CONVERSION TO MILS COMP ON REVERSE IF USING MILS] (NORTH +, SOUTH −)	+ 6 14 93		
18	APPARENT DECLINATION OF SUN [(14) OF AUE COMP ON REVERSE]	+ 3 57 13		
19	ALGEBRAIC SUM (17) AND (18)	+ 9 72 06		
20	1/2 OF (19)	+ 4 86 03		

* IF (5) IS: (+) AND LESS THAN 24 HRS → GREENWICH DATE (6) IS: LOCAL DATE; (+) AND MORE THAN 24 HRS → LOCAL DATE + 1 DAY; (−) → LOCAL DATE − 1 DAY. AND GMT (6) IS: SAME AS (5) (+) → (5) − 24 HRS; (−) → 24 HRS − (5)

		SET HR 1	SET HR	SET HR
21	REPEAT (17)	+ 6 14 93		
22	REPEAT (18) WITH OPPOSITE SIGN	− 3 57 13		
23	ALGEBRAIC SUM (21) AND (22)	+ 2 57 80		
24	1/2 OF (22)	+ 1 28 90		
25	LOG COS (24)	9.996 5132		
26	LOG COT (14)	0.404 8053		
27	(25) + (26)	0.401 3185		
28	LOG SIN (20)	9.662 0560		
29	(27) − (28)	0.739 2625		
30	ANGLE HAVING LOG TAN (29)	1 416 35		
31	LOG SIN (24)	9.101 0930		
32	REPEAT (26)	0.404 8053		
33	(31) + (22)	9.505 8983		
34	LOG COS (20)	9.948 5613		
35	(22) − (34)	9.557 3370		
36	ANGLE HAVING LOG TAN (25)	3 52 75		
37	REPEAT (20)	14 16 35		
38	IF (20) AND (24) HAVE SAME SIGNS, USE (36) + (27); IF (20) AND (24) HAVE OPPOSITE SIGNS, SUBTRACT SMALLER (36) OR (27), FROM LARGER, (27) OR (36)	17 69 10		
39	WHEN STATION IS IN NORTH LATITUDE: IF (19) IS (+) → (29) IS {360° (6400 mils) − (38) REPEAT}; IF (19) IS (−) → (29) IS (38). SOUTH LATITUDE: IF (19) IS (+) → (29) IS {180° (3200 mils) + (38)}; IF (19) IS (−) → {180° (3200 mils) − (38)}	17 69 100		
40	MEAN HORIZONTAL ANGLE	75 650		
41	(39) − (40) = ASTRONOMIC AZIMUTH TO MARK	16 93 450		

COMPUTER	NISBETT	CHECKER	HERZOG
SHEET 1 OF 1 SHEETS	POST CREEK	AREA	A-2
NOTEBOOK REFERENCE			

DA FORM 1 JAN 56 6-10 PREVIOUS EDITION OF THIS FORM IS OBSOLETE.

Figure 14–31. Completed DA Form 6–10. (front).

CONVERSION COMPUTATION *(TABLE 5)*

HOURS, MINUTES AND SECONDS (TIME) TO DEGREES, MINUTES AND SECONDS OR MILS (ARC)

		SET NR 1	SET NR	SET NR	
1	(1) OF COMPUTATION	3 h 41 m 34 s	h m s	h m s	1
2	DEGREES OR MILS IN HOURS OF (1)	8 00 00			2
3	DEGREES AND MINUTES OR MILS IN MINUTES OF (1)	1 82 22			3
4	MINUTES AND SECONDS OR MILS IN SECONDS OF (1)	2 52			4
5	(2)+(3)+(4) (ENTER IN (15) ON FRONT)	9 84 74			5

CONVERSION TO MILS COMPUTATION *(USE TABLE III b OF TM 6-230)*

1	LONGITUDE (FROM FRONT OF FORM)	98° 22' 24"	10	LATITUDE (FROM FRONT OF FORM)	34° 35' 25"
2	th IN HUNDREDS OF DEGREES OF (1)		11	th IN TENS OF DEGREES OF (10)	5 33.33
3	th IN TENS OF DEGREES OF (1)	16 00.00	12	th IN UNITS OF DEGREES OF (10)	71.11
4	th IN UNITS OF DEGREES OF (1)	1 42.22	13	th IN TENS OF MINUTES OF (10)	8.89
5	th IN TENS OF MINUTES OF (1)	5.93	14	th IN UNITS OF MINUTES OF (10)	1.48
6	th IN UNITS OF MINUTES OF (1)	0.59	15	th IN TENS OF SECONDS OF (10)	0.10
7	th IN TENS OF SECONDS OF (1)	0.10	16	th IN UNITS OF SECONDS OF (10)	0.02
8	th IN UNITS OF SECONDS OF (1)	0.02		SUM OF (11) THROUGH (16) [ENTER IN (17) ON FRONT AND ON DA FORM 5-20]	6.14.93
9	SUM OF 15) THROUGH 18) [ENTER IN (15) ON FRONT AND ON DA FORM 6-20]	17.48.86	17		

AUXILIARY COMPUTATION FOR APPARENT DECLINATION OF SUN AT GREENWICH DATE AND GMT

		SET NR 1	SET NR	SET NR	
1	GREENWICH DATE [(6) OF COMPUTATION]	23 Jul 1962			1
2	GMT [HOURS AND MINUTES IN (6) OF COMPUTATION]	HRS 15 MIN 48	HRS MIN	HRS MIN	2
		X60	X60	X60	
3	NUMBERS OF HOURS IN (2) X 60	900			3
4	NUMBER OF MINUTES IN (2)	48			4
5	(3)+(4)	948			5
6	DAILY CHANGE IN DECLINATION (TABLE 2)	± 3.61	±	±	6
7	LOG OF (5)	2.976 8083			7
8	LOG OF (6)	0.557 5072			8
9	LOG OF CONSTANT	6.841 6375	6.841 6375	6.841 6375	9
10	(7)+(8)+(9)	0.375 9530			10
11	NUMBER HAVING LOG (10) = SECONDS OR MILS OF CHANGE	2.38			11
12	APPARENT DECLINATION AT 0h ON GREENWICH DATE (TABLE 2)	± 3 59.51	±	±	12
13	(11) CONVERTED TO MINUTES AND SECONDS OR (11) IN MILS [USE SIGN OF (6)]	± 2.38	±	±	13
14	ALGEBRAIC SUM (12) AND (13) ENTER IN (16) ON FRONT	± 3 57.13	±	±	14

GIVEN:

Time zone of area of operation.

FIELD DATA:

Latitude and longitude of station.
Approximate azimuth to azimuth mark.
Local date of observation.
Mean watch time of observation and watch correction to nearest second.
Horizontal clockwise angle from azimuth mark to sun.

GUIDE:

Enter observed field data in block marked. [ ]
When using a mil-graduated instrument, --

a. (2) through (5) of CONVERSION COMPUTATION are computed using hundredth-mil values.
b. (2) through (9) and (11) through (17) of CONVERSION TO MILS COMPUTATION are computed using hundredth-mil values.
c. (12) through (24) of computation are computed using hundredth-mil values.
d. (6) through (14) of AUXILIARY COMPUTATION are computed using hundredth-mil values.
e. (25) through (41) of computation are computed using tenth-mil values.

Value in (41) should be about equal to approximate azimuth to azimuth mark.
Continue computations using DA Form 6-20 to obtain the UTM grid azimuth.

LIMITATIONS:

This form is not to be used when accuracies greater than fourth-order are required.
The hour-angle method should not be used when the sun is more than 60 degrees above horizon.

RESULTS:

A value of astronomic azimuth for each set of observations.

FORMULAS:

$$\tan 1/2\,(A+q) = \frac{\cos 1/2\,(Lat - Dec)}{\sin 1/2\,(Lat + Dec)} \cot 1/2\,t$$

$$\tan 1/2\,(A-q) = \frac{\sin 1/2\,(Lat - Dec)}{\cos 1/2\,(Lat + Dec)} \cot 1/2\,t$$

A = astonomic azimuth of sun measured east or west of meridian.

q = parallactic angle (cancels in computations).

Lat = latitude of station.

Dec = apparent declination of sun.

t = hour angle (less than 12^h) of sun.

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Figure 14–32. Completed DA Form 6–10 (back).

b. Determination of Greenwich Apparent Time. Greenwich apparent time (GAT) is obtained by applying the equation of time and the value from the equation of time graph to the Greenwich mean time. Greenwich apparent time is the time that has elapsed since the apparent (real) sun last made a lower transit of the Greenwich meridian (fig 14–30). The equation of time is the difference between mean solar time and apparent solar time.

c. Determination of Greenwich Hour Angle. The Greenwich hour angle (GHA) is the time that has elapsed since the sun last crossed the Greenwich meridian. Greenwich apparent time is always 12 hours more or 12 hours less than the Greenwich hour angle; therefore, to determine the Greenwich hour angle, either add or subtract 12 hours from Greenwich time (fig 14–30).

d. Determination of Local Hour Angle. The local hour angle of a celestial body is the time that has elapsed since the celestial body last crossed the observer's meridian. The angle at the pole is the local hour angle of the body if the body is west of the meridian, or it is 360° minus the local hour angle if the body is east of the meridian.

14–41. Formula for the Hour-Angle Solution

Several formulas can be derived for the solution of the spherical triangle when two sides and the included angle are known. A formula, selected for the convenience of using logarithms, is as follows:

$$\tan \tfrac{1}{2}(A+q) = \frac{\cos \tfrac{1}{2}(\text{lat-dec}) \cot \tfrac{1}{2}t}{\sin \tfrac{1}{2}(\text{lat} + \text{dec})}$$

$$\tan \tfrac{1}{2}(A-q) = \frac{\sin \tfrac{1}{2}(\text{lat-dec}) \cot \tfrac{1}{2}t}{\cos \tfrac{1}{2}(\text{lat} + \text{dec})}$$

where A = astronomic azimuth east or west of meridian
q = parallactic angle
lat = latitude of station
dec = apparent declination of sun
t = hour angle (less than 12^h).

Note. DA Form 6–10 has been designed for the solution of the above formula.

14–42. DA Form 6–10

DA Form 6–10 (Computation—Astronomic Azimuth by Hour-Angle Method, Sun) (fig 14–31 and 14–32) is divided into nine general parts—marginal data, lines 1–6, lines 7–16, lines 17–24, lines 25–30, lines 31–38, and lines 39–41 on the front and the auxiliary computations on the guide and the guide on the back.

a. Marginal Data. Blocks are provided on the front of the form for recording the latitude and longitude of the station, approximate azimuth to azimuth mark, local date, azimuth mark, station, computer, checker, sheet number, notebook references, area and date.

b. Lines 1 through 6. On lines 1 through 6, entries are made for the determination of the Greenwich date and mean time from the watch time of the observation.

c. Lines 7 through 16. On lines 7 through 16, the local hour angle is determined by first computing the Greenwich apparent time.

d. Lines 17 through 24. On lines 17 through 24, the values of $\frac{1}{2}$(lat—dec) and $\frac{1}{2}$(lat+dec) are determined.

e. Lines 25 through 30. On lines 25 through 30, the value of tan $\frac{1}{2}(A+q)$ in the formula is solved.

f. Lines 31 through 38. The value of tan $\frac{1}{2}$(A—q) in the formula is solved on line 36. On line 38, the value of the azimuth angle is determined.

g. Lines 39 through 41. On lines 39 through 41, the value of A is converted to the azimuth to the sun, and the measured angle is subtracted to determine the azimuth to the mark.

h. Auxiliary Computation. On the back of the form, the auxiliary computations are made for the declination of the sun at the time of the observation. The results of these computations are entered on line 18 on the front of the form.

i. Guide. The guide on the back of the form provides information concerning field data, limitations, results and formulas.

14–43. Example of Computing Azimuth by the Hour-Angle Method (Sun)

a. Given Data.

(1) Station: BOWL.
(2) Azimuth mark: TS 1.
(3) Local date: 23 July 62.
(4) Celestial body observed: Sun.
(5) Time zone correction: +6 hours.
(6) Latitude: Latitude: 34°35′25″ N.
Longitude: 98°22′24″ W.
Grid coordinates: (557470–3827590).
(7) Watch: 12 seconds slow.
(8) Approximate azimuth to azimuth mark: 1,690 mils.
(9) Mean data of observation from field notebook:

Watch time: $9^h47^m44^s$
Horizontal angle: 75.650 mils

b. Solution. See figures 14–31 and 14–32.

Section VI. AZIMUTH BY THE HOUR-ANGLE METHOD (STARS)

14–44. The Hour-Angle Method (Star)

a. General. The hour-angle method may be used with observations on Polaris or on east-west stars. This method, used with Polaris, yields the most accurate fourth-order azimuths. When the hour-angle method is used with east-west stars, its requirement for accurate time is a disadvantage, but it can be used where no stars meet the position requirements for the altitude method.

b. Position of the Stars for Observation. East-west stars for hour-angle observations are selected by using the star finder and the star rate templates (app E). Polaris may be observed any time it is visible, but best results are obtained when it is above 175 mils in altitude, to minimize the effects of horizontal refraction.

14–45. Observation and Identification of Polaris

a. Orbit of Polaris. Polaris appears to move in a small, elliptical, counterclockwise orbit about the celestial north pole. The size of this apparent orbit varies slightly with the observer's latitude; at latitude 35° north, its minor diameter is about 45 mils. Because Polaris stays so close to the north celestial pole, it is visible throughout the night in most of the Northern Hemisphere. When the Polaris local hour angle is 0 or 12 hours, the star is sadi to be in its upper or lower culmination, respectively. When the Polaris local hour angle is 6 or 18 hours, the star is said to be in its western or eastern elongations, (fig 14–33). Polaris' small orbit results in very slow apparent motion, so the star may be observed at any point in its orbit. The least chance of error in tracking, however, will occur when the star is in elongation.

b. Identification of Polaris.

(1) Polaris is the brightest star in the constellation Ursa Minor (the Little Dipper), which is near the constellations Ursa Major (the Big

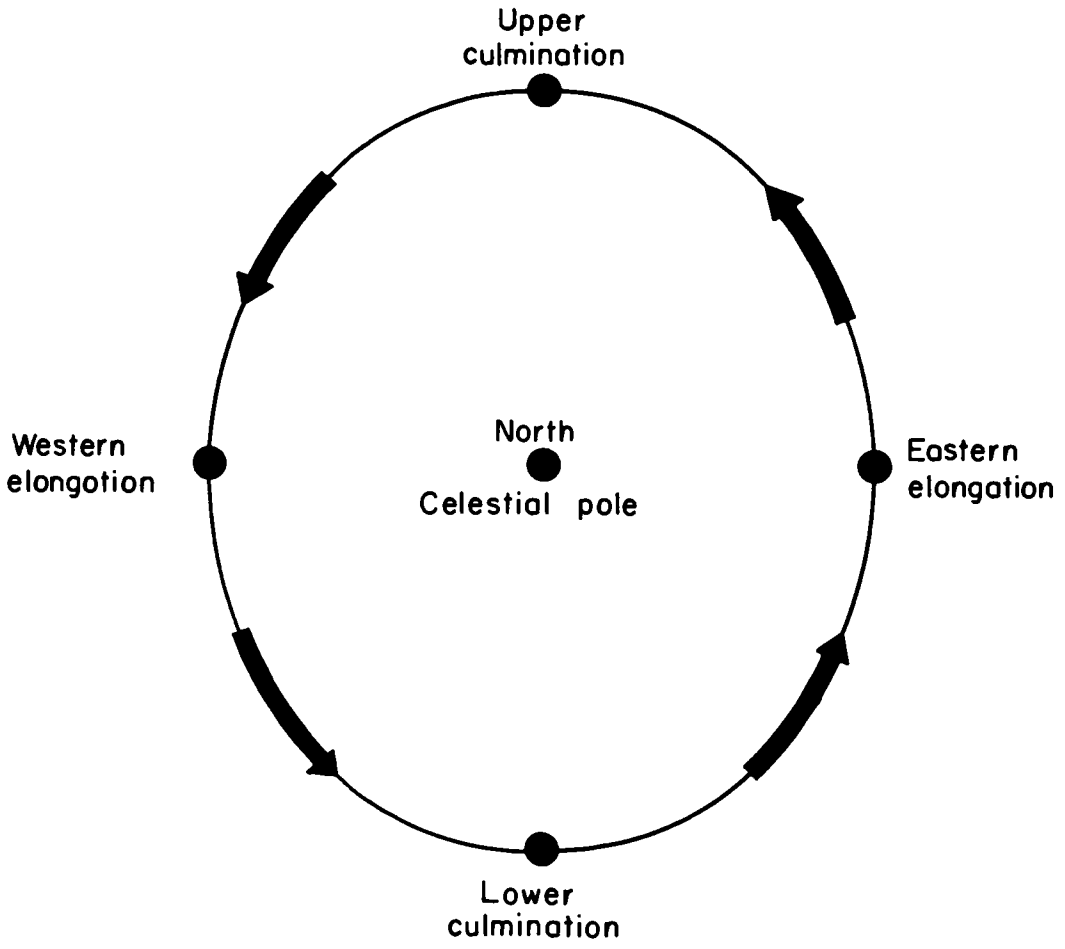


Figure 14–33. Orbit of Polaris.

Dipper) and Cassiopeia. Polaris is the end star of the three stars making up the "handle" of the Little Dipper, which is visible on very clear nights. Polaris can also be identified with respect to Ursa Major and Cassiopeia (fig 14–34). The two stars forming the side of the bowl farthest from the handle of the Big Dipper are called the "pointer stars". An imaginary line extended through the pointer stars toward Cassiopeia nearly passes through the celestial north Pole. Polaris is approximately five times the distance between the pointer stars along the imaginary line from the Big Dipper. Since the constellation Cassiopeia is on the same side of the celestial north pole as Polaris, its position relative to the pole is approximately the same as Polaris', and the constellation can be used to determine which part of its orbit Polaris is in.

(2) As an aid in identifying Polaris, set the latitude of the observer's position as a vertical angle on the observing instrument and point the telescope north; the line of sight will be near the celestial north pole, and, since Polaris is very near the pole, the star should appear in the field of view. If the star is in elongation, its altitude will equal the observer's latitude. When Polaris is moving from eastern to western elongation, its altitude is greater than the latitude of the observer, but, when it is moving from western to eastern elongation, its altitude is less than the latitude of the observer.

(3) When the telescope is directed at Polaris, the observer will see two other stars nearby which are not visible to the naked eye. However, Polaris will be the only star visible when the cross-hairs are lighted.

14–46. Solving the Azimuth

The solution of the celestial triangle using the hour-angle method with a star is the same as when the sun is observed (para 14–39*a*), except that sidereal time is used to find the hour angle (fig 14–35).

a. Formula for Solving the Astronomic Triangle by the Hour-Angle Method (Star).

$$\tan \tfrac{1}{2}(A+q) = \frac{\cos \tfrac{1}{2}(\text{lat} - \text{dec}) \cot \tfrac{1}{2}t}{\sin \tfrac{1}{2}(\text{lat} + \text{dec})}$$

$$\tan \tfrac{1}{2}(A-q) = \frac{\sin \tfrac{1}{2}(\text{lat} - \text{dec}) \cot \tfrac{1}{2}t}{\cos \tfrac{1}{2}(\text{lat} + \text{dec})}$$

where A = astronomic azimuth of star measured east or west of meridian
q = parallactic angle
lat = latitude of station
dec = declination of star
t = interior angle at the pole. Angle "t" equals the local hour angle when the celestial body is in the west; angle t equals 24 hours minus the local angle when the body is in the east.

b. Determination of Hour Angle. The general steps for converting standard time of observation to local hour angle are as follows:

(1) Local mean time to Greenwich mean time, to Greenwich sidereal time, to Greenwich hour angle, to local hour angle. In figure 14–35 it can be seen that—

(*a*) Right ascension is the arc measured

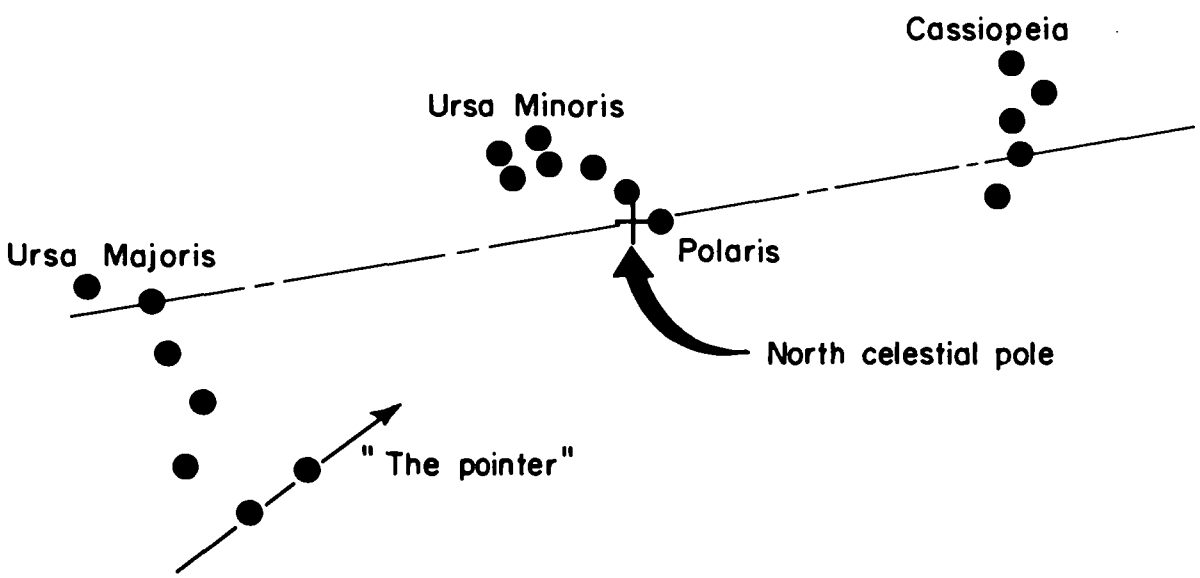


Figure 14–34. Identification of Polaris.

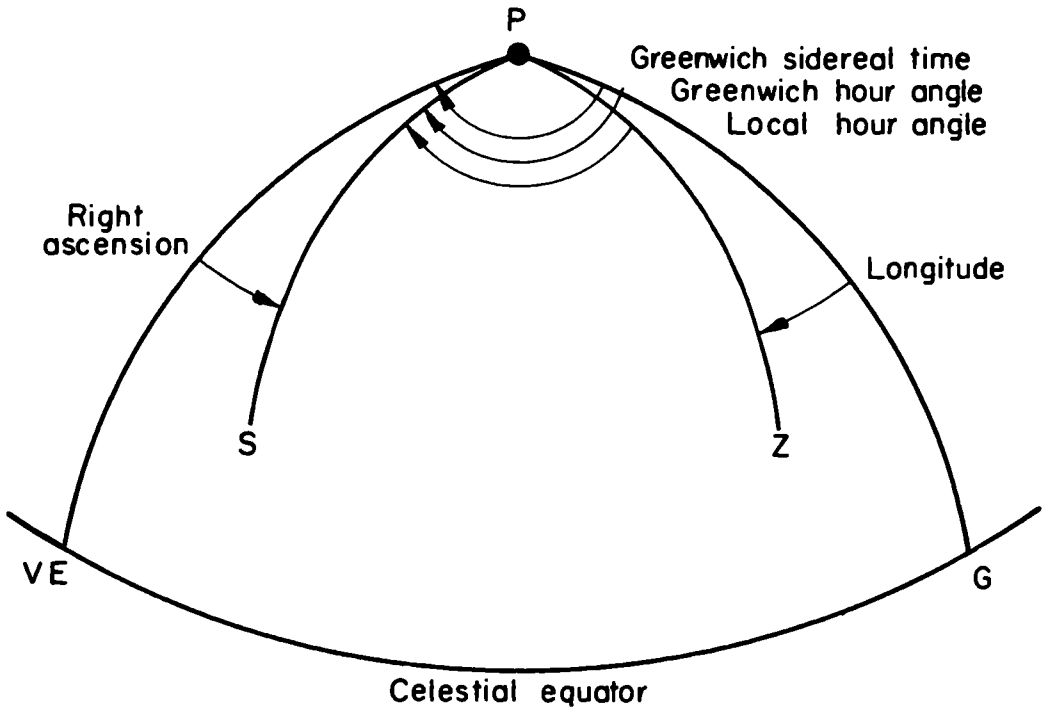


Figure 14–35. Hour angle from sidereal time.

eastward from the vernal equinox (VE) to the hour circle of the celestial body (S).

(*b*) Greenwich sidereal time is the time elapsed since the vernal equinox last crossed the Greenwich meridian (G).

(*c*) Greenwich hour angle is the time elapsed since the celestial body last crossed the Greenwich meridian.

(*d*) Local hour angle is the time elapsed since the celestial body last crossed the observer's meridian (Z).

(*e*) The arc from the Greenwich meridian to the observer's meridian is equal to the longitude of the observer's station.

(2) The steps performed on DA Form 6–10a in determining the local hour angle are as follows:

Corrected watch time
\+ time zone correction
= Greenwich mean time
\+ sidereal time for 0^h GMT (Army Ephemeris, table 2)
\+ correction for GMT (table 4)
= Greenwich sidereal time
— right ascension of star (Army Ephemeris)
= Greenwich hour angle
± longitude
= local hour angle.

14–47. DA Form 6–10a

DA Form 6–10a (Computation—Astronomic Azimuth by Hour-Angle Method, Star) (fig 14–36 and 14–37) is designed for computations by the hour-angle method when a star has been observed. The form is divided into nine general parts for discussion—marginal data, the determination of Greenwich mean time and date, Greenwich sidereal time, Greenwich hour angle, local hour angle, ½(lat—dec) and ½(lat+dec), ½(A+q) and ½(A—q), the astronomic azimuth of body and astronomic azimuth to mark, and the guide.

a. Marginal Data. Spaces are provided on the front of the form for recording the latitude and longitude of the station, approximate azimuth to the azimuth mark, local date, azimuth mark, station, computer, checker, sheet number, notebook reference, area and date.

b. Determination of Greenwich Mean Time. On lines 1 through 6, the Greenwich mean time and date are computed from the watch time of the observation and the time zone correction.

c. Greenwich Sidereal Time. On lines 7 through 9, Greenwich sidereal time is determined by adding GMT, sidereal time at 0^h GMT, and sidereal time fo GMT.

d. Greenwich Hour Angle. On lines 10 and 11, the right ascension is subtracted from Greenwich sidereal time to obtain the Greenwich hour angle.

COMPUTATION - ASTRONOMIC AZIMUTH BY HOUR-ANGLE METHOD, STAR (FM 6-2) — TABLE NRS REFER TO TM 6-300- 1962

STAR NAME AND NR (TABLE 9): POLARIS, NR 10

LATITUDE OF STATION: 34° 39' 48" N — LONGITUDE OF STATION: 98° 24' 18" W — APX AZ TO AX MK: 4270 — LOCAL DATE: 15 Apr 62 — AZIMUTH MARK: TS 26 — STATION: TS 25

		SET NR 1	SET NR	SET NR
1	MEAN WATCH TIME OF OBSERVATION	20 13 22		
2	WATCH CORRECTION (SLOW +, FAST −)	+ 01		
3	ALGEBRAIC SUM (1) AND (2)	+ 20 13 23		
4	TIME ZONE CORRECTION (W LONG +, E LONG −)	+ 6		
5	ALGEBRAIC SUM (3) AND (4)	+ 26 13 23		
	GREENWICH DATE * 16 Apr 1962	24 00 00	24 00 00	24 00 00
6	GREENWICH MEAN TIME (GMT) *	2 13 23		
7	SIDEREAL TIME AT 0h ON GREENWICH DATE (TABLE 2)	13 34 38		
8	CORRECTION TO (7) (TABLE 4)	22		
	(4)+(7)+(8) [IF GREATER THAN 24 HRS, SUBTRACT 24 HRS. RESULT WILL BE GREATER THAN (10). OTHERWISE, IF LESS THAN (10), ADD 24 HRS.]	15 48 23 24 00 00	24 00 00	24 00 00
9		15 48 23		
10	RIGHT ASCENSION OF STAR (TABLE 10, 10-MILS, ON 11)	1 56 13		
11	(9) - (10)	13 52 10		
12	(11) CONVERTED TO ARC [(5) OF CONV COMP ON REVERSE]	36 98 52		
13	LONGITUDE [(9) OF CONVERSION TO MILS, COMP ON REVERSE IF USING MILS] (EAST +, WEST −)	− 17 49 43		
14	ALGEBRAIC SUM (12) AND (13)	− 19 49 09		
	IF (14) IS: (−) 0° TO +180° / +180° TO 360° / MORE THAN 360° — (15) IS: REPEAT (14) / 360° − (14), SIGN (−) / (14) − 360°, SIGN (+)			
15		− 19 49 09		
16	1/2 OF (15)	− 9 74 54		
17	LATITUDE [(17) ON CONVERSION TO MILS, COMP ON REVERSE IF USING MILS] (NORTH +, SOUTH −)	− 6 16 24		
18	DECLINATION OF STAR OR GREENWICH DATE (TABLE 10, 10-MILS, ON 11)	− 15 83 77		
19	ALGEBRAIC SUM (17) AND (18)	− 22 00 01		
20	1/2 OF (19)	− 11 00 00		

* IF (5) IS: (+) AND LESS THAN 24 HRS; (+) AND MORE THAN 24 HRS; (−) — GREENWICH DATE (6) IS: LOCAL DATE; LOCAL DATE + 1 DAY; LOCAL DATE −1 DAY — AND GMT (6) IS: SAME AS (5); (5) − 24 HRS; 24 HRS − (5)

		SET NR 1	SET NR	SET NR
21	REPEAT (17)	− 6 16 24		
22	REPEAT (18) WITH OPPOSITE SIGN	+ 15 83 77		
23	ALGEBRAIC SUM (21) AND (22)	+ 9 67 53		
24	1/2 OF (23)	+ 4 83 76		
25	LOG COS (24)	9 949 052		
26	LOG COT (16)	9 848 198		
27	(25) + (26)	9 797 250		
28	LOG SIN (20)	9 945 430		
29	(27) − (28)	9 851 820		
30	ANGLE HAVING LOG TAN (29)	6 29 5		
31	LOG SIN (24)	9 660 212		
32	REPEAT (26)	9 848 198		
33	(31) + (32)	9 508 410		
34	LOG COS (20)	9 673 386		
35	(33) - (34)	9 835 024		
36	ANGLE HAVING LOG TAN (35)	6 11 0		
37	REPEAT (30)	6 29 5		
38	IF (20) AND (24) HAVE SAME SIGNS, USE (36)+(37)	6 11 0		
	IF (20) AND (24) HAVE OPPOSITE SIGNS, SUBTRACT SMALLER, (36) OR (37), FROM LARGER, (37) OR (36)	18 5		
39	WHEN STATION IS IN NORTH LATITUDE: IF (15) IS (+) USE (38); IF (15) IS (−) REPEAT (38) — SOUTH LATITUDE: IF (15) IS (+) 180° − (38); IF (15) IS (−) (38) − 180°	64 00 00 18 5 63 81 5		
40	MEAN HORIZONTAL ANGLE	20 62 6		
41	(39) − (40) = ASTRONOMIC AZIMUTH TO MARK	43 18 9		

COMPUTER: KRUCK — CHECKER: BAKER — SHEET 1 OF 1 SHEETS

DA FORM 6-10a (OCT 62) — REPLACES DA FORM 6-10a, 1 JAN 58, EXISTING SUPPLIES OF WHICH WILL BE ISSUED AND USED UNTIL 1 OCT 64 UNLESS SOONER EXHAUSTED

62-4-15 — PINE VALLEY — C-4

Figure 14–86. Completed DA Form 6–10a (front).

CONVERSION COMPUTATION *(TABLE 5)*

HOURS, MINUTES AND SECONDS (TIME) TO DEGREES, MINUTES AND SECONDS OR MILS (ARC)

		SET NR 1	SET NR	SET NR	
1	(11) OF COMPUTATION	13 h 52 m 10 E	h m E	h m E	1
2	DEGREES OR MILS IN HOURS OF (1)	34 , 66 , 67			2
3	DEGREES AND MINUTES OR MILS IN MINUTES OF (1)	2 , 31 , 11			3
4	MINUTES AND SECONDS OR MILS IN SECONDS OF (1)	0 , 74			4
5	(2)+(3)+(4) [ENTER IN (12) ON FRONT]	36 , 98 , 52			5

CONVERSION TO MILS COMPUTATION *(USE TABLE III b OF TM 6-230)*

1	LONGITUDE [FROM FRONT OF FORM]	98° 24' 18"	10	LATITUDE [FROM FRONT OF FORM]	34° 39' 48"
2	∅ IN HUNDREDS OF DEGREES OF (1)		11	∅ IN TENS OF DEGREES OF (10)	5 , 33 . 33
3	∅ IN TENS OF DEGREES OF (1)	16 , 00 . 00	12	∅ IN UNITS OF DEGREES OF (10)	, 71 . 11
4	∅ IN UNITS OF DEGREES OF (1)	1 , 42 . 22	13	∅ IN TENS OF MINUTES OF (10)	, 8 . 89
5	∅ IN TENS OF MINUTES OF (1)	, 5 . 93	14	∅ IN UNITS OF MINUTES OF (10)	, 2 . 67
6	∅ IN UNITS OF MINUTES OF (1)	, 1 . 19	15	∅ IN TENS OF SECONDS OF (10)	, 0 . 20
7	∅ IN TENS OF SECONDS OF (1)	, 0 . 05	16	∅ IN UNITS OF SECONDS OF (10)	, 0 . 04
8	∅ IN UNITS OF SECONDS OF (1)	, 0 . 04		SUM OF (11) THROUGH (16) [ENTER IN (17) ON FRONT AND ON DA FORM 6-20]	6 , 16 . 24
9	SUM OF (2) THROUGH (8) [ENTER IN (13) ON FRONT AND ON DA FORM 6-20]	17 , 49 . 43	17		

GIVEN:

Time zone of area of operation.

FIELD DATA:

Latitude and longitude of station.
Approximate azimuth to azimuth mark.
Name(s) and number(s) of selected star(s).
Local date of observation.
Mean watch time of observation and watch correction to nearest second.
Horizontal clockwise angle from azimuth mark to star.

GUIDE:

Enter observed field data in block marked.

When using a mil-graduated instrument, --

a. (2) through (5) of CONVERSION COMPUTATION are computed using hundredth-mil values.
b. (2) through (9) and (11) through (17) of CONVERSION TO MILS COMPUTATION are computed using hundredth-mil values.
c. (12) through (24) of computation are computed using hundredth-mil values.
d. (25) through (41) of computation are computed using tenth-mil values.

Value in (41) should be about equal to approximate azimuth to azimuth mark.
Continue computations using DA Form 6-20 to obtain the UTM grid azimuth.

LIMITATIONS:

This form should not be used when accuracies greater than fourth-order are required.
The hour-angle method should not be used when the star is more than 60 degrees above horizon.

RESULTS:

A value of astronomic azimuth for each set of observations.

FORMULAS:

$$\tan 1/2\,(A+q) = \frac{\cos 1/2\,(Lat - Dec)}{\sin 1/2\,(Lat + Dec)} \cot 1/2\,t$$

$$\tan 1/2\,(A-q) = \frac{\sin 1/2\,(Lat - Dec)}{\cos 1/2\,(Lat + Dec)} \cot 1/2\,t$$

A = astronomic azimuth of star measured east or west of meridian.

q = parallactic angle (cancels in computations).

Lat = latitude of station.

Dec = declination of star.

t = hour angle (less than 12^h) of star.

Figure 14-37. Completed DA Form 6-10a (back).

e. Local Hour Angle. On lines 12 through 16, the longitude is subtracted from the Greenwich hour angle to obtain the local hour angle. One-half of the hour angle is determined on line 16.

f. Value of ½(Lat—Dec) and ½(Lat+Dec). On lines 17 through 24, latitude and declination are combined to determine ½(lat—dec) and ½(lat+dec).

g. Value of ½(A+q) and ½(A—q). On lines 25 through 36, the formula is solved by using logarithms.

h. Astronomic Azimuth of Body and Astronomic Azimuth to Mark. On lines 37 through 41, the value of the azimuth angle is determined and converted to azimuth if necessary; the horizontal angle from the mark to the star is subtracted from the azimuth to the star to obtain the azimuth to the mark.

i. Guide. The guide on the back of the form includes field data, limitations, results, and formulas.

14–48. Example of Computing Azimuth by the Hour-Angle Method (Star)

a. Given Data.

(1) Station: TS 25.
(2) Azimuth mark: TS 26.
(3) Local date: 15 April 1962.
(4) Celestial body observed: Polaris (No. 10).
(5) Time zone correction: +6 hours.
(6) Latitude: 34°39′48″ N
Longitude: 98°24′18″ W
Grid coordinates: (554460.0–3835590.0.
(7) Watch: 1 second slow.
(8) Approximate azimuth to mark: 4,270 mils.
(9) Mean data of observation from field notebook:
Watch time: $20^h13^m22^s$
Horizontal angle: 2,062.6 mils.

b. Solution. See figures 14–36 and 14–37.

Section VII. AZIMUTH BY THE POLARIS TABULAR METHOD

14–49. General

The computational methods discussed in sections IV, V, and VI are satisfactory for both fourth- and fifth-order work. When only fifth-order accuracy is required and Polaris is observable, much time can be saved by using the Polaris tabular method. The Polaris tabular method uses the azimuths to Polaris tabulated in table 12 of the Army Ephemeris. These azimuths are corrected by factors related to the observer's latitude and the date and time of observation. The method is limited to fifth-order accuracy by the construction of table 12, not by any weakness inherent in the method. The Polaris tabular method is the preferred method for fifth-order astronomic azimuth determination because of the simple computations and because Polaris' slow apparent motion makes tracking easy.

14–50. Computation of Azimuth

a. Local Sidereal Time. The local sidereal time of observation must be computed to enter table 12. Local sidereal time is found by algebraically adding the observer's longitude, in units of time, to the Greenwich sidereal time of observation. When the observer's longitude is east, its sign is plus; when the observer's longitude is west, its sign is minus. Greenwich sidereal time may be determined as in paragraph 14–46*b*(2), or by computing lines 1 through 9 on DA Form 6–10a. The observer's longitude is converted to units of time by using table 5b in the Army Ephemeris (TM 6–300–70 and subsequent).

Example: Convert $20^h\ 15^m07^s$ local mean time (LMT) on 13 April 1962 to local sideral time (LST). The observer's longitude is 13°51′42″ E.

Solution:

(1) Compute Greenwich sideral time:

LMT	=	$20^h15^m07^s$
Time zone correction	=	$-1^h00^m00^s$
GMT 13 Apr 1962	=	$19^h15^m07^s$
GST at 0h GMT	=	$13^h22^m48^s$
Correction to GST	=	3^m10^s
		$32^h41^m05^s$
		$-24^h00^m05^s$
GST 13 April 1962		$8^h41^m05^s$

(2) Convert observer's longitude into time:

Hours and minutes in degrees of longitude (13°)	=	0^h52^m
Minutes and seconds in minutes of longitude (51′)	=	3^m24^s
Seconds in seconds of longitude (42″)	=	3^s
Longitude in time	=	$0^h55^m27^s$

(3) Compute local sidereal time:

Greenwich sidereal time	=	$8^h41^m05^s$
Observer's longitude (east)	=	$+0^h55^m27^s$
Local sidereal time	=	$9^h36^m32^s$

b. Extract b0, b1, and b2. Enter table 12 with the local sidereal time of observation and extract b0 ,b1, and b2 (para 14–30).

c. Computation of Final Azimuth to Polaris. Algebraically add b0, b1, and b2 and divide the sum by the cosine of the observer's latitude. (Since the secant $= \frac{1}{\text{cosine}}$, division by cosine latitude is the same as multiplication by secant latitude, as shown at the bottom of table 12.) The quotient is the azimuth angle to Polaris in minutes of arc, which is converted to mils by adding the log conversion factor 9.471726–10 to the log of the azimuth angle. Using the sign of b0 + b1 + b2, algebraically add the azimuth angle to 6400 to get the azimuth to Polaris. Subtract the mean horizontal angle from the azimuth mark to Polaris from the azimuth to Polaris to get the azimuth to the mark.

Example: Find the azimuth to the azimuth mark on 13 April 1962 at $20^h15^m07^s$ LMT. The mean horizontal angle to Polaris is 1,317.1 mils; the observer is located at latitude 37°42′17″ N, longitude 13°51′42″ E.

Solution:

(1) b0, b1, b2, (LST = $9^h36^m32^s$):

b0	=	−49.2′
b1	=	− 0.1′
b2	=	0.0′
b0 + b1 + b2	=	−49.3′

(2) Compute the azimuth angle:

Log (b0 + b1 + b2)	=	1.692847
Log cosine latitude (37°42′17″)	=	−9.898274
		1.794573
Log conversion factor	=	+9.471726
Log azimuth angle	=	1.266299
Azimuth angle		−18.5 mils

(3) Compute the azimuth to the mark:

		6,400 mils
Azimuth angle	= −	18.5 mils
Azimuth to Polaris	=	6,381.5 mils
Mean horizontal angle	=	−1,317.1 mils
Azimuth to the mark	=	5,064.4 mils

d. Convergence. The azimuth obtained by this method is a true azimuth. Before using this azimuth in survey computations it must be converted to a grid azimuth, using DA Form 6–20.

Section VIII. STAR SELECTION AND IDENTIFICATION

14–51. General

a. Stars have important advantages over the sun as sources of astronomic azimuth. Since they appear as pinpoints of light in instrument telescopes, stars are easier to track than the sun. With 73 stars tabulated in the Army Ephemeris, one can usually be found in a satisfactory position for observation, regardless of the time of night or the observer's latitude.

b. Polaris should always be used when the geographical location and tactical situation permit. Polaris is the most desirable source of astronomic azimuth because it is easily identified and because its slow apparent motion makes it easy to track. The Polaris tabular method yields reliable fifth-order azimuths in considerably less time than any other method. The Polaris hour-angle method gives the most accurate results of any fourth-order azimuth method used by the artillery.

c. In the low northern latitudes and the Southern Hemisphere, however, east-west (non-circumlar) stars must be used for night astronomic azimuth determination. Local weather conditions obscuring Polaris may also make observation of east-west stars necessary. Since so many stars are available for observation, the artillery surveyor must be able to select and identify those most suitable for observation, and the star identifier (para 14–52) and world star charts are used to identify them.

14–52. Star Finder and Identifier

The star finder and identifier (fig 14–38) is a device used to determine the approximate (±2°) azimuth and altitude of a given star. The item is issued as a component of surveying set, artillery fire control, fourth order. The star finder and identifier consists of a base with stars of the Northern Hemisphere on one side and stars of the South-

ern Hemisphere on the other; 10 templates; and a carrying case. The templates are graduated for every 10° of latitude, from 5° to 85°. (The tenth template, designed for plotting the sun and planets, is not used in artillery survey.) The template constructed for the latitude nearest the latitude of the observer should be used. The base of the star finder in figure 14–38 shows the stars visible in the Northern Hemisphere. The center of the device represents the celestial north pole. Around the periphery of the base is a circle graduated in degrees and half degrees, representing the local hour angle of the vernal equinox or the local sidereal time. Around the circumference of the template are two sets of figures from 0° to 360°, a set starting from the bottom and another set starting from the top. In the Northern Hemisphere, the inner figures are used; in the Southern Hemisphere, the outer figures are used. The inner set of figures represents the azimuth from the celestial north pole to the line which the figures identify. The set of outer figures represents the same thing, with the exception that the azimuth is from celestial south pole to the line. The series of concentric ellipses represent altitudes above the horizon. The template has the horizon on its circumference, the zenith as its center, and a measure of azimuth around the edge. The 0° – 180° line represents the observer's meridian. Before the star finder can be oriented, the value of the local sidereal time must be determined. The pointer of the template is placed over the appropriate value on the base of the star finder. Local sidereal time can be determined by using DA Form 6–21, the Army Ephermeris, or special tables.

14–53. DA Form 6–21

DA Form 6–21 (Computation and Instructions for Use With Star Identifier) (fig 14–39 and 14–40), has been designed for orienting the star finder and identifier and for recording azimuths and altitudes of selected stars at selected times.

14–54. Example of Orienting the Star Finder

a. Given Data.

(1) Time zone: S.
(2) Latitude: 35° N.
(3) Longitude: 98° W.
(4) Station: MIKE.
(5) Local date: 8 July.
(6) Watch time: 2100 hours.

b. Solution. See figures 14–39 and 14–40.

14–55. Selection of Stars for Observation

a. Star Rate.

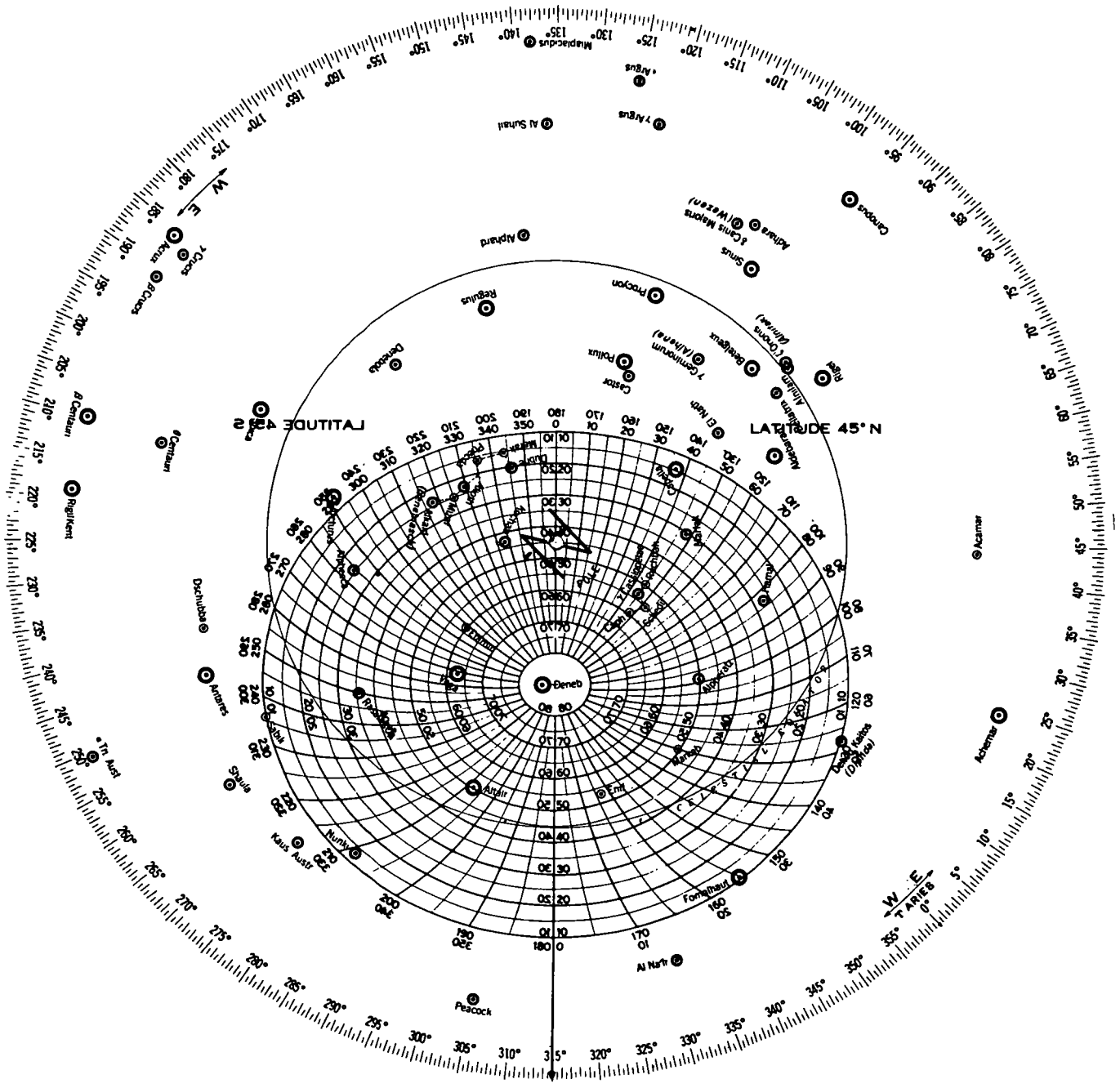
(1) The apparent motion of a celestial body has two components—a horizontal motion, representing change in azimuth, and a vertical motion, representing change in altitude. An error in measuring the altitude of a celestial body will result in a final azimuth error related to the ratio between the two components of the body's apparent motion (fig 14–41). When a star is moving at a small angle to the horizon, an error in measuring the altitude will result in a greater error in final azimuth than it would if the star were moving at a large angle to the horizon, as shown in figure 14–42. This relationship is called the star rate, which is the ratio of resulting azimuth error to error in vertical measurement. A star which changes in altitude but not in azimuth will have a star rate of 0, since an error in altitude measurement will result in no error in azimuth. A star which changes so rapidly in azimuth and so slowly in altitude that a 1-mil error in altitude measurement will result in a 3-mil azimuth error will have a star rate of 3.

(2) For altitude method observations, select the stars with the lowest star rates, since both azimuth and altitude are measured. Low star rates are not essential for hour-angle observations because altitude is not measured; however, stars with low star rates will be moving more slowly in azimuth and will be easier to track than those with high star rates. Although Polaris has a high star rate in its culminations, its apparent motion is so slow that it can be successfully observed at any time. Avoid observing stars below 175 mils in altitude because of possible errors caused by horizontal refraction.

b. Star Rate Plates. Full-scale star rate curve templates appear in appendix E. These star rate curves should be traced on the appropriate star identifier plates with a grease pencil. Only the curves of immediate interest should be traced on the template, since the full set of curves may be confusing. These curves are used to determine which stars will be the best for observation at the time azimuth determination is required. The star rate curves divide the sky into the following areas:

(1) *Area A.* Stars in area A have rates between 0 and 0.5. These are the best stars for observation and should be used whenever possible. The dotted line represents a star rate of 0.

(2) *Area B.* Stars in area B have rates between 0.5 and 1.0. Acceptable fourth-order azi-


LATITUDE 45° N
LATITUDE 45° S
Deneb
Altair
Fomalhaut
Peacock
Al Na'ir
Nunki
Kaus Austr
Antares
Dschubba
Rasalhague
Kochab
Alphecca
Vega
Rastaban
Eltanin
Kaus Media
Kaus Borealis
Sabik
Ras Alhague
Etamin
Arcturus
Alphard
Regulus
Procyon
Pollux
Castor
Sirius
Rigel
Capella
Canopus
Achernar
Acamar
Rigil Kent
Hamal
Diphda
Menkar
Alpheratz
Markab
Schedir
Caph
Navi
Mirfak
Algol
Dubhe
Merak
Phecda
Megrez
Alioth
Mizar
Alkaid
Polaris
Kochab
Miaplacidus
Al Suhail

COMPUTATION AND INSTRUCTIONS FOR USE WITH STAR IDENTIFIER

For use of this form, see FM 6-2; the proponent agency is U.S. Continental Army Command.

TIME ZONE	LATITUDE OF STATION	LONGITUDE OF STATION	STATION
S	35 °N S	98 °E W	MIKE

		SCHEDULE 1	SCHEDULE 2	SCHEDULE 3	SCHEDULE 4	
1	PRESELECTED LOCAL DATE 8 Jul					1
2	PRESELECTED WATCH TIME 2100					2
3	LONGITUDE OF STATION (EAST +, WEST −)	⊖ 98				3
4	LONGITUDE OF CENTRAL MERIDIAN (FROM TABLE I ON REVERSE) (EAST −, WEST +)	⊕ 90				4
5	ALGEBRAIC SUM (3) AND (4)	⊖ 8				5
6	SETTING FOR 0h ON LOCAL DATE (FROM TABLE II ON REVERSE)	285				6
7	CORRECTION TO (6) FOR WATCH TIME (FROM TABLE III OH REVERSE	316				7
8	(6)+(7)	+ 601				8
9	REPEAT (5)	⊖ 8				9
10	ALGEBRAIC SUM (8) AND (9)	+ 593 ⊕ 593				10
11	ORIENTATION ANGLE IF 10 IS: (−) 0° TO 360° MORE THAN 360° (11) IS: 360° (10) REPEAT (10) (10) − 360°	360 233 233				11

SET POINTER OF APPROPRIATE TEMPLATE ON ORIENTATION ANGLE (SEE GUIDE ON REVERSE)

12	NAME OF STAR ALTAIR					12
13	APRX AZIMUTH OF STAR	98°				13
14	CONVERT (13) TO MILS, IF NECESSARY					14
15	APRX ALTITUDE OF STAR	27°				15
16	CONVERT (15) TO MILS, IF NECESSARY					16
12	NAME OF STAR DENEBOLA					12
13	APRX AZIMUTH OF STAR	263°				13
14	CONVERT (13) TO MILS, IF NECESSARY					14
15	APRX ALTITUDE OF STAR	36°				15
16	CONVERT (15) TO MILS, IF NECESSARY					16
12	NAME OF STAR SPICA					12
13	APRX AZIMUTH OF STAR	220°				13
14	CONVERT (13) TO MILS, IF NECESSARY					14
15	APRX ALTITUDE OF STAR	35°				15
16	CONVERT (15) TO MILS, IF NECESSARY					16
12	NAME OF STAR VEGA					12
13	APRX AZIMUTH OF STAR	70°				13
14	CONVERT (13) TO MILS, IF NECESSARY					14
15	APRX ALTITUDE OF STAR	53°				15
16	CONVERT (15) TO MILS, IF NECESSARY					16

COMPUTER	CHECKER	SHEET	OF	SHEETS
CPL SMITH	PVT BROWN	1	1	

DA FORM 1 FEB 56 6-21 PREVIOUS EDITIONS OF THIS FORM ARE OBSOLETE.

Figure 14–39. Completed DA Form 6–21 (front).

TABLE I

TIME ZONE	LONG OF MERIDIAN
EAST	LONG
Z	0°
A	15
B	30
C	45
D	60
E	75
F	90
G	105
H	120
I	135
K	150
L	162
M	180
WEST	LONG
Z	0°
N	15
O	30
P	42
Q	60
R	75
S	90
T	102
U	120
V	122
W	150
X	165
Y	150

TABLE II

DAY OF MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	DAY OF MONTH
	MONTH												
1	100°	121°	158°	189°	215°	249°	275°	209°	268°	9°	40°	69°	1
2	101	122	159	190	219	250	279	210	241	10	41	70	2
3	102	122	160	191	220	251	280	211	342	11	42	71	3
4	103	124	161	192	221	252	251	212	242	12	42	72	4
5	104	125	162	193	222	222	252	212	244	12	44	73	5
6	105	126	163	194	222	224	283	214	245	14	45	76	6
7	106	127	164	192	224	252	284	212	246	12	46	75	7
8	107	127	165	196	225	226	285	216	247	16	47	76	8
9	108	128	166	197	226	257	286	217	248	17	45	77	9
10	109	129	167	198	227	228	287	218	249	18	49	78	10
11	110	140	168	199	228	229	288	219	250	19	50	79	11
12	111	141	169	200	229	260	259	220	250	20	51	80	12
13	112	142	170	201	230	261	290	221	221	21	22	81	13
14	113	142	171	202	221	262	291	222	352	22	22	82	14
15	114	144	172	202	222	262	292	222	253	22	54	52	15
16	115	142	173	204	222	264	292	224	254	24	55	84	16
17	116	146	174	204	224	265	294	225	255	22	26	85	17
18	117	147	175	202	225	266	295	226	256	26	27	86	18
19	118	148	176	206	236	267	298	227	257	27	58	87	19
20	119	149	177	207	227	288	297	228	255	28	29	85	20
21	120	150	178	208	228	269	298	229	259	29	60	59	21
22	121	121	179	209	229	270	299	220	0	20	61	90	22
23	122	152	180	210	240	271	200	221	1	21	82	91	23
24	122	152	181	211	241	272	201	222	2	22	63	92	24
25	124	124	182	212	242	273	202	222	2	33	62	92	25
26	122	155	183	212	242	274	202	234	4	24	64	94	26
27	126	126	184	214	244	272	204	335	2	22	65	95	27
28	127	157	182	212	242	276	202	226	6	36	66	96	28
29	128	158	186	216	246	277	206	227	7	27	67	97	29
30	129		187	217	247	277	207	228	5	28	68	98	30
31	120		188		248		208	229		39		99	31

TABLE III

WATCH TIME	CORR
0h	0°
1	15
2	30
3	45
4	60
5	75
6	90
7	105
8	120
9	135
10	150
11	165
12	181
13	198
14	211
15	228
16	241
17	256
18	271
19	286
20	301
21	316
22	331
23	346

GIVEN:

Time zone of area of operation.
Latitude and longitude of station to nearest degree.
Preselected local date of observation.
Preselected watch time of observation to nearest hour.

GUIDE:

When observation is to be made at other than preselected watch time ((2) of computation), increase orientation angle ((11) of computation) 1 degree for each 4 minutes of elapsed time after the hour or decrease orientation angle 1 degree for each 4 minutes of time before the hour.
Select stars between 20 and 45 degrees (60 degrees if a special eyepiece is available) above horizon and within 30 degrees of a 90-degree or 270-degree azimuth (east - west line) to use the altitude method.
Select four stars for each schedule, two in the east and two others in the west.
Read APRX AZIMUTH and APRX ALTITUDE of stars from template of star identifier to nearest degree.
When using a mil-graduated instrument, convert APRX AZIMUTH and APRX ALTITUDE to mils using table III b of TM 6-230.

LIMITATIONS:

The altitude and hour-angle methods should not be used when the star is more than 60 degrees above horizon.

RESULT:

APRX AZIMUTH and APRX ALTITUDE for four schedules of four stars each at preselected watch times.

Figure 14-40. DA Form 6-21 (back).

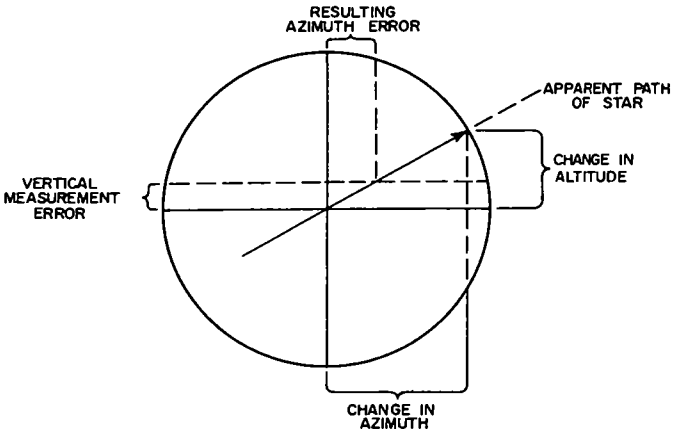


Figure 14–41. Motion of a star viewed through a surveying instrument—high star rate.

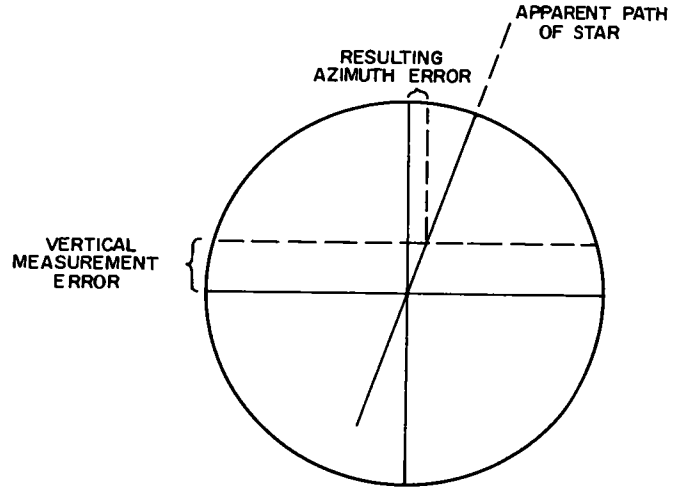


Figure 14–42. Motion of a star viewed through a surveying instrument—low star rate.

the stars at definite coordinates. Consequently, on a star chart, the north-south location of a star is fixed by declination, and the east-west location is fixed by right ascension.

b. There are two projections by which star charts are plotted—cylindrical (similar to the Mercator projection for world maps) and plane (similar to Polar projection for world areas). The cylindrical projection presents great distortion about the poles of the celestial sphere but offers a fairly accurate picture in declination to plus or minus 65°. It should be remembered that in such a projection the vertical lines plotted to be parallel are actually convergent at the poles and perpendicular to the Equator. The plane projection presents a truer picture of the sky, especially if it is used with a mark which blocks out all the sky except that which is within the horizon for a given area.

c. The brightness of stars is measured in magnitude. Thus, the brightest stars are of the first magnitude; the next in brightness are the second magnitude, etc. Stars in constellations, some of which have individual names (e.g., Polaris), are usually named in the constellation in order of their brightness through the use of the Greek alphabet. Thus, in the constellation Orion, from the brightest to the least bright, the stars are named Betelgeuse, Rigel, Bellatrix, etc. The magnitude of stars is shown on star charts.

14–57. Locating Stars

The easiest means of identifying the stars and fixing their locations in relation to others is to learn something about constellations. Since stars are fixed indefinite points in the sky with relation to each other, the realtive position of stars has remained about the same for many centuries. In certain groups of stars, primitive star gazers saw the shapes of creatures or heroes of their folklore. Names were applied to the shapes of these various groups of stars. Later, people saw in the stars the shapes of household implements with which they worked. The development of the names of stars began early in the history of man and finally resulted in the rudimentary catalog of the visible stars. The named shapes became "constellations", and the individual stars were identified by name with the constellation of which they were a part. From this primitive development, Latin names were given the constellation, and other groups of stars were assigned names of gods and goddesses and creatures of land and sea that figures in Roman and Greek mythology. Much later in history, our forefathers saw in the many constellations objects common to their mode of living. Thus, the Big Bear came to be known as the Big Dipper. To the English, the same constellation is the Plough.

a. The familiar constellation called the Big Dipper is only part of the constellation Ursa Major (fig 14–43). The dipper's seven stars are easy to find on almost any clear night. The two outer stars of the bowl point toward the North Star, Polaris, which is about 30° away. The distance between the pointers is about 5°. Both measurements are very helpful when the star finder and identifier is being used.

b. Cassiopeia (fig 14–44), sometimes called the Lady in the Chair, the Running W, or the Lazy M,

is a prominent northern constellation. It is found directly across the north celestial pole, opposite the Big Dipper. When the Big Dipper is below the horizon, Polaris can be found by bisecting the acute angle formed by the brightest stars in Cassiopeia; the bisecting line points almost through Polaris.

c. Polaris, the pole star, is the alpha star in the constellation Ursa Minor (fig 14–45), commonly called the Little Dipper. On a clear night, the Little Dipper is easily seen. The handle of the dipper has a reverse curve, and Polaris is the last star in the handle.

d. The first prominent constellation after the vernal equinox (VE) has risen in the east is *Taurus,* the Bull (fig 14–46). On the forehead of *Taurus* is a red star of the first magnitude, *Aldebaran.* It is a royal star, one of the four stars most commonly used by navigators. On the upper foreleg of *Taurus* are the *Pleiades.* This aggregation is a tight cluster of stars grouped together; it is also called the Seven Sisters.

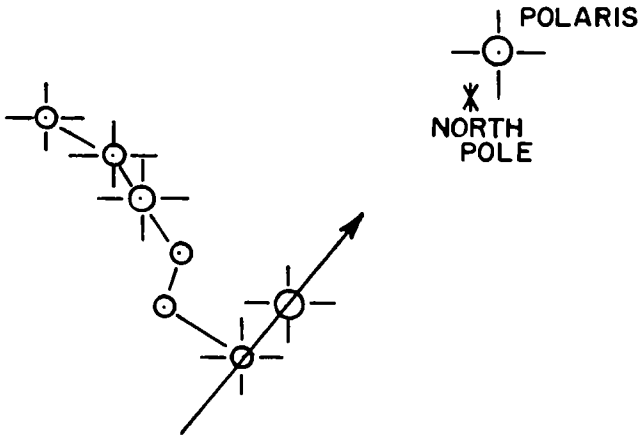


Figure 14–43. Ursa Major.

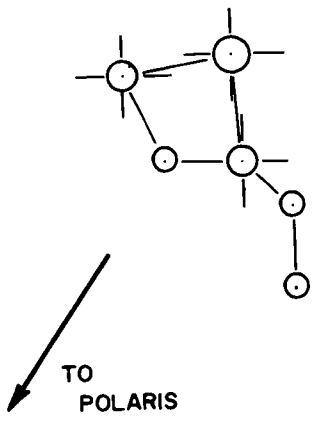


Figure 14–44. Cassiopeia.

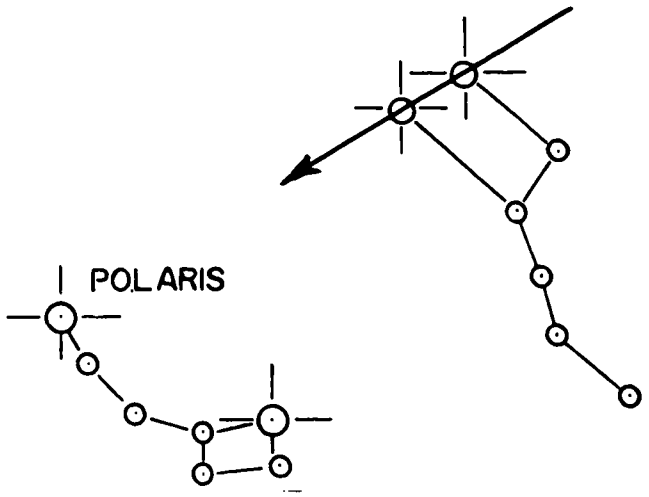


Figure 14–45. Ursa Minor.

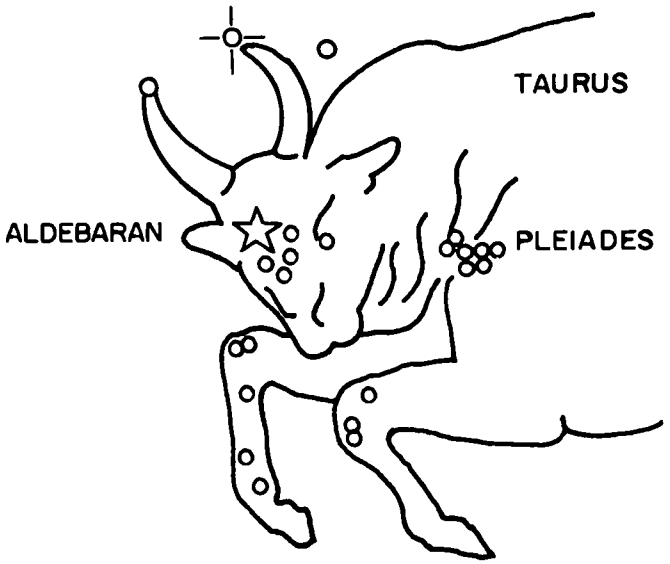


Figure 14–46. Taurus.

e. Chasing these seven stars and the bull at the same time is *Orion,* the Hunter (fig 14–47). There are two very bright stars in Orion. The hunter's right shoulder is *Betelgeuse* (Orionis); his left knee is *Rigel* (Orionis). Close on the heels of Orion are his two dogs, Canis Major and Canis Minor. In the big dog is the brightest star in the sky, *Sirius.* If it is observed carefully, it is found to be a brilliant blue-white. Slightly behind Canis Major is the smaller dog in which Procyon is found.

f. At about the same right ascension with the canine constellation is *Gemini,* The Twins (fig 14–48). Think of Gemini as a wedge pointed toward Orion. The brighter star at the base of the wedge is *Pollus* (Geminorum); the one above it is *Castor* (Geminorum).

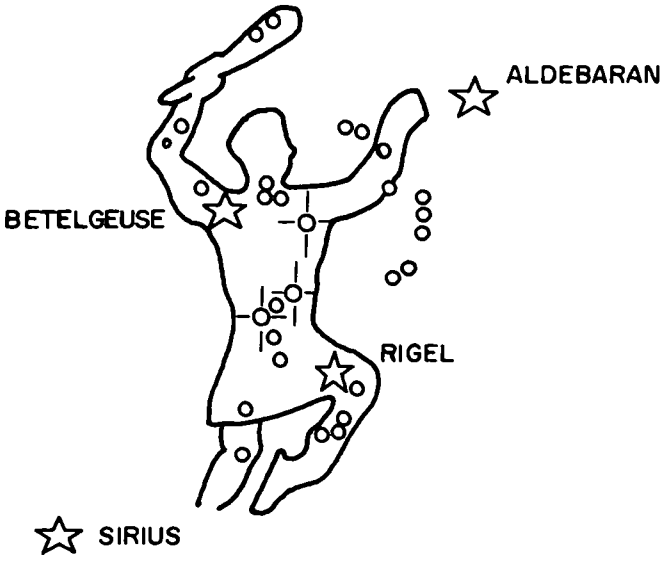


Figure 14–47. Orion.

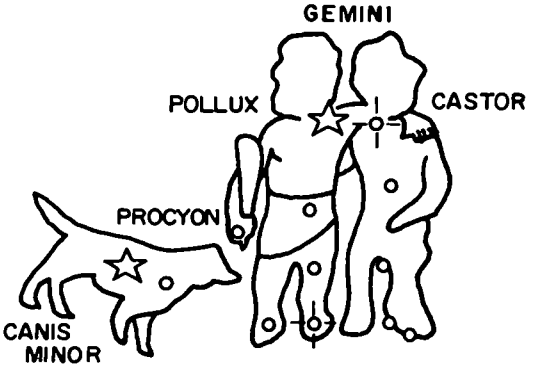


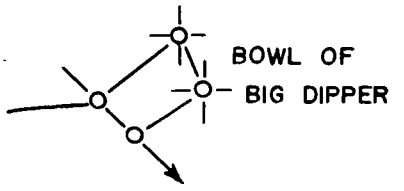
Figure 14–48. Gemini.

g. About 2 hours behind Gemini and Canis Minor is *Leo,* the Lion (fig 14–49). The head and forequarters of Leo are sometimes referred to as the Sickle. The body and tail extend off to the east. The heart of Leo is *Regulas* (Leonis). *Regulas* is another of the four royal stars; it is a brilliant white, whereas the others are red.

h. As soon as Leo is well up in the sky, Virgo (fig 14–50) will rise in the east. The bright star in Virgo is called *Spica* (Virginia) and makes approximately an equilateral triangle with *Denebola* (Leonis) and Arcturus (Bootis). This triangle is sometimes referred to as the Virgo triangle.

i. One of the most easily recognized constellations is *Scorpio* (fig 14–51). However, it is so far south that, in northern latitudes, it is visible during evening hours only through July and August. *Antares* (Scorpii) is another of the four royal stars.

j. Very close to the circumpolar region, the Northern Cross, *Cygnus,* is to be found (fig 14–52). This is a very prominent constellation, and, in northern latitudes, it will be nearly overhead in the evening in the fall. The head of the cross is *Deneb* (Cygni). There are two neighbor stars in this sector of the sky—*Vega* (Lyrae), which rises just before the cross, and *Altair* (Acquilae), which trails it somewhat to the south. Cygnus is imagined by some to be a cross; to others, it takes the shape of a swan from which the name is derived. Lyra is in the shape of a harp and Acquila resembles an eagle.



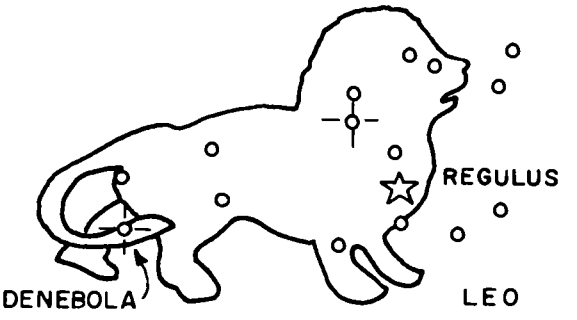


Figure 14–49. Leo.

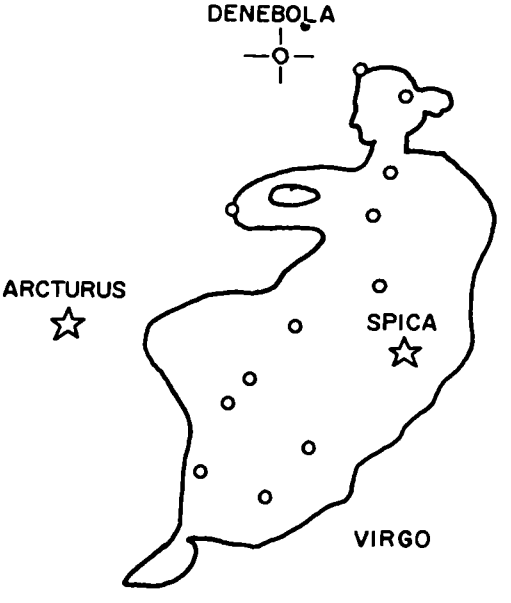


Figure 14–50. Virgo.

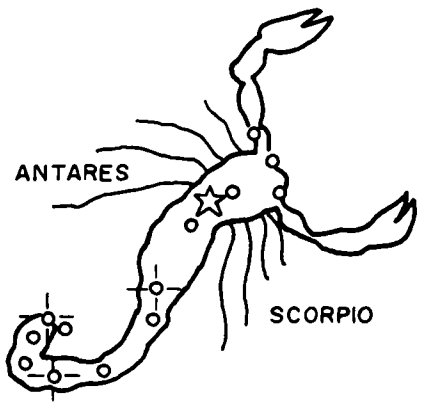


Figure 14–51. Scorpio.

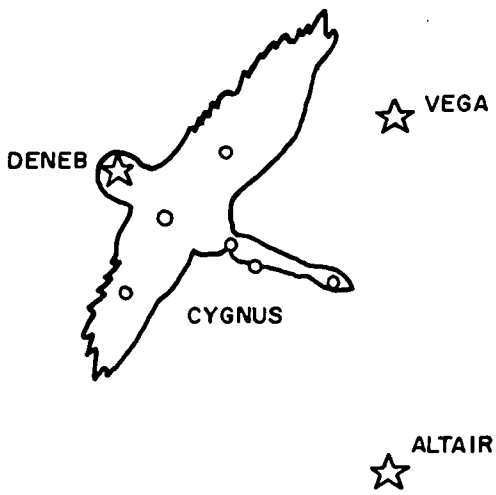


Figure 14–52. Cygnus.

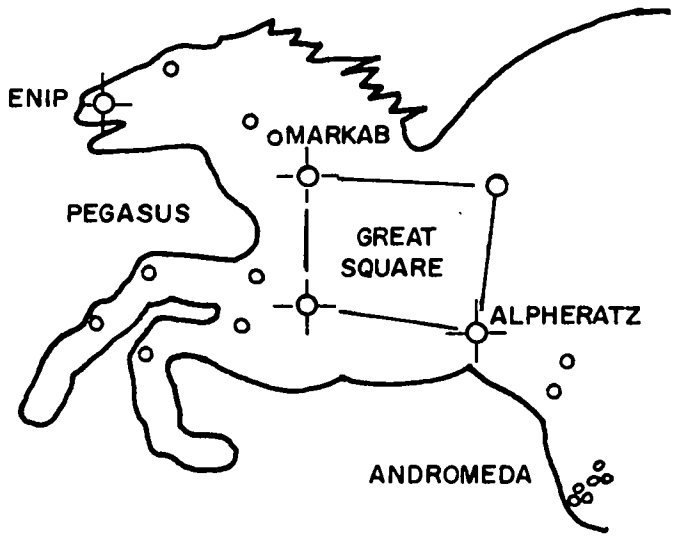


Figure 14–53. Pegasus.

k. Pegasus (fig 14–53), the Great Square, straddles the hour circle of the vernal equinox. This is the constellation of the flying horse, a very prominent sky mark.

l. Formalhaut, the fourth royal star, is a prominent star in the southern sky. It ranks number 13 in brightness of stars visible in the Northern Hemisphere.

Section IX. SELECTION OF METHODS OF OBSERVATION

14–58. Fifth-Order Azimuths

a. Generally, speed of computation is the most important consideration when choosing a method for fifth-order astronomic azimuth determination. The techniques covered in paragraphs 14–31 through 14–50 will give satisfactory fifth-order azimuth determination.

b. At night, Polaris should always be used, if it is observable, because it is easy to identify and easy to track. When observing Polaris, use the Polaris tabular method. If Polaris is not visible but an east-west star is, either the altitude or the hour-angle method can be used. If the star has a high star rate and accurate time is available, use the hour-angle method. If the star has a low rate, the altitude method is generally preferable because it requires less accurate time than does the hour-angle method. If time is not critical and only east-west stars are observable, observe a star in the east and one in the west.

c. In the daytime, use the sun-altitude method if the sun is in the proper position, since accurate time is not so important as it is with the hour-angle method. If the sun is too low to use the altitude method, the hour; angle method must be used.

14–59. Fourth-Order Azimuths

a. Generally, the prime consideration in choosing a method for fourth-order azimuth determination is accuracy. The hour-angle method is theoretically more accurate than the altitude method, but this accuracy depends in turn on the availability of accurate time.

b. The best source of fourth-order accuracy is the Polaris hour-angle method. (Polaris is never

observed by the altitude method.) Polaris is easily identified and tracked, and when the hour-angle method is used with Polaris, accurate time is not so critical as it is when used with an east-west body. When Polaris is unobservable, observe an east-west star with the hour angle method if accurate time is available. If time is unreliable, use the altitude method of observation.

c. In the daytime use the hour-angle method with the sun if accurate time is available; if not, use the altitude method.

Section X. CONVERSION OF ASTRONOMIC AZIMUTH TO GRID AZIMUTH

14–60. Convergence

The azimuth determined by observing a celestial body is an astronomic, or true, azimuth. This azimuth must be converted to grid azimuth for use in artillery survey. The difference between true azimuth and grid azimuth (fig 14–54) is called grid convergence. The sign of grid convergence correction is *plus* when the observer's station is west of the central meridian and *minus* when the station is east of the central meridian (fig 14–55). Grid azimuth is determined by algebraically adding the true azimuth and the value of grid convergence.

14–61. Determination of Convergence

Convergence is a function of both latitude and longitude. Its value should be computed by using both the geographic coordinates and grid coordinates. The formula for determining convergence is shown on the back of DA Form 6–20 (Computation—Convergence (Astronomic Azimuth to UTM Grid Azimuth). If the two determinations of azimuth agree within the tolerance specified on the form, the value determined through grid coordinates is used as the grid convergence.

14–62. DA Form 6–20

DA Form 6–20 is divided into seven general parts—marginal data, convergence through geographic coordinates, convergence through grid coordinates, and application to astronomic azimuth on the front (fig 14–56) and the table of central meridians, conversion computation, and guide on the back (fig 14–57).

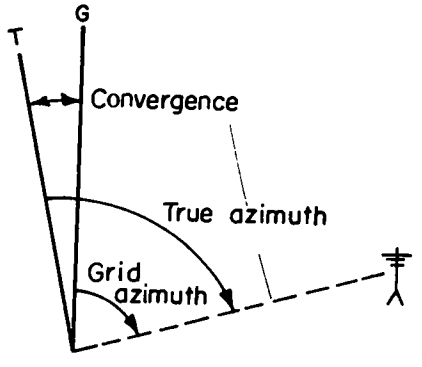


Figure 14–54. Relation of true azimuth to grid azimuth.

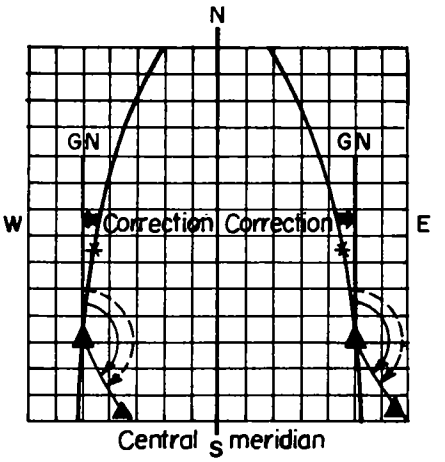


Figure 14–55. Convergence.

a. Marginal Data. Spaces are provided on the front of the form for recording the station designation, azimuth mark, grid and geographic coordinates, computer, checker, sheet number, notebook reference, area and date.

b. Convergence through Geographic Coordinates. Lines 1 through 10 provide for the solution of the formula: convergence $= (XII)_p + (XIII)_p 3$.

c. Convergence through Grid Coordinates. Lines 11 through 22 provide for the solution of the formula: convergence $= (XV)_q - (XVI)_q 3$.

d. Application to Astronomic Azimuth. Lines 24 through 33 permit meaning several astronomic azimuths and applying convergence.

e. Table of Central Meridians. UTM grid zone numbers and longitudes of central meridians in degrees and mils are on the back of the DA Form 6–20.

f. Conversion Computation. Below the table of central meridians, lines 1 through 8 provide for the conversion of degrees, minutes, and seconds to seconds, and lines 9 through 18 provide for the

COMPUTATION - CONVERGENCE (ASTRONOMIC AZIMUTH TO UTM GRID AZIMUTH)

(Table Numbers Refer to TM 6-300- 1962)
(FM 6-2)

STATION: TS 20	AZIMUTH MARK: TS 21
LONGITUDE OF STATION: 98 24 18 (E/W)	UTM GRID ZONE: 14
EASTING OF STATION: 554 460	
LATITUDE OF STATION: 34 39 48 (N/S)	NORTHING OF STATION: 3 835 590

1	LONGITUDE OF STATION (Mils)	17 49 43	11	EASTING OF STATION	554 460
2	LONGITUDE OF CENTRAL MERIDIAN (FROM TABLE ON REVERSE)	17 60 00	12		500 000
3	IF (1) IS: MORE THAN (2) → (1) − (2); LESS THAN (2) → (2) − (1)	17 49 43 / 10 57	13	IF (11) IS: MORE THAN (12) → (11) − (12); LESS THAN (12) → (12) − (11)	/ 54 460
4	IF (1) IS IN DEGREES, USE (8) OF CONVERSION COMP ON REVERSE IF (1) IS IN MILS, REPEAT (3)	10 .57	14	REPEAT (13) WITH DECIMAL POINT MOVED LEFT SIX PLACES	0.054 460
5	LOG (4)	1.024 075	15	LOG (14)	8.736 078
6	LOG SIN LATITUDE OF STATION	9.754 901	16	LOG OF FUNCTION XV (TABLE 6)	4.349 239
7	(5) + (6)	0.778 976	17	(15) + (16)	3.085 317
8	NUMBER HAVING LOG (7) = FIRST TERM IN SECONDS OR MILS	6.01	18	LOG CONVERSION SECONDS TO MILS	7.693 575
9	SECOND TERM (TABLE 8 OR 8-MILS, USE (2) AND LATITUDE)	.	19	IF (1) IS IN DEGREES, REPEAT (17) IF (1) IS IN MILS, USE (17) + (18)	0.778 892
10	(8) + (9) = CONVERGENCE IN SECONDS OR MILS. WHEN STATION IS IN NORTH LATITUDE AND... IF (1) IS: MORE THAN (2) → (10) IS: IN WEST LONG +, IN EAST LONG −; LESS THAN (2) → IN WEST LONG −, IN EAST LONG +. WHEN STATION IS IN SOUTH LATITUDE AND... IF (1) IS: MORE THAN (2) → IN WEST LONG −, IN EAST LONG +; LESS THAN (2) → IN WEST LONG +, IN EAST LONG −.	± 6.01	20	NUMBER HAVING LOG (19) = FIRST TERM IN SECONDS OR MILS	6.01
			21	SECOND TERM (TABLE 7, USE (11) AND NORTHING)	.
			22	(20) − (21) = CONVERGENCE IN SECONDS OR MILS. WHEN STATION IS IN NORTH LATITUDE: IF (11) IS: MORE THAN (12) → (22) IS −; LESS THAN (12) → +. WHEN STATION IS IN SOUTH LATITUDE: IF (11) IS: MORE THAN (12) → (22) IS +; LESS THAN (12) → −	± 6.01

IF (10) AND (22) DIFFER BY MORE THAN {0.4" / 0.02 mil} REDETERMINE COORDINATES AND RECOMPUTE ALL COMPUTATIONS

23	CONVERGENCE	IF (1) IS IN DEGREES, USE (18) OF CONVERSION COMP ON REVERSE IF (1) IS IN MILS, REPEAT (22)	± 6.01

SUMMARY OF ASTRONOMIC AZIMUTHS AND COMPUTATION OF UTM GRID AZIMUTH

		ASTRONOMIC AZIMUTH TO AZIMUTH MARK		REMARKS
24	SET NR 1	43 18 63		
25	SET NR 2			
26	SET NR 2			
27	SET NR			
28	SET NR			
29	SET NR			
30	SUM	43 18 63		
31	MEAN (SIGN +)	+ 43 18 63	+	
32	CONVERGENCE REPEAT (22)	± 6 01	+ −	
33	ALGEBRAIC SUM OF (31) AND (32) = GRID AZIMUTH TO MARK	43 12 62		

COMPUTER: KRUCK	CHECKER: BAKER	SHEET 1 OF 1 SHEETS
NOTEBOOK REFERENCE: C-2-62	AREA: LEMON BLUFF	DATE: 15-4-62

DA FORM 1 FEB 56 6-20 REPLACES DA FORM 6-20, 1 OCT 52; AND DA FORM 6-24, 1 SEP 52, WHICH ARE OBSOLETE.

Figure 14-56. Completed DA Form 6-20 (front).

TABLE – CENTRAL MERIDIAN OF UTM GRID ZONES

ZONE NR	DEGREES W LONG	MILS W LONG	ZONE NR	DEGREES W LONG	MILS W LONG	ZONE NR	DEGREES E LONG	MILS E LONG	ZONE NR	DEGREES E LONG	MILS E LONG
1	177	3146.67	16	87	1546.67	31	3	53.33	46	93	1653.33
2	171	3040.00	17	81	1440.00	32	9	160.00	47	99	1760.00
3	165	2933.33	18	75	1333.33	33	15	266.67	48	105	1866.67
4	159	2826.67	19	69	1226.67	34	21	373.33	49	111	1973.33
5	153	2720.00	20	63	1120.00	35	27	480.00	50	117	2080.00
6	147	2613.33	21	57	1013.33	36	33	586.67	51	123	2186.67
7	141	2506.67	22	51	906.67	37	39	693.33	52	129	2293.33
8	135	2400.00	23	45	800.00	38	45	800.00	53	135	2400.00
9	129	2293.33	24	39	693.33	39	51	906.67	54	141	2506.67
10	123	2186.67	25	33	586.67	40	57	1013.33	55	147	2613.33
11	117	2080.00	26	27	480.00	41	63	1120.00	56	153	2720.00
12	111	1973.33	27	21	373.33	42	69	1226.67	57	159	2826.67
13	105	1866.67	28	15	266.67	43	75	1333.33	58	165	2933.33
14	99	1760.00	29	9	160.00	44	81	1440.00	59	171	3040.00
15	93	1653.33	30	3	53.33	45	87	1546.67	60	177	3146.67

CONVERSION COMPUTATION

	DEGREES, MINUTES, AND SECONDS TO SECONDS	° ′ ″		SECONDS TO DEGREES, MINUTES, AND SECONDS	
1	REPEAT (3)		9	REPEAT (22) OF COMPUTATION	
2	NUMBER OF DEGREES IN (1)		10	NUMBER OF TIMES 3600 DIVIDES INTO (9) = NUMBER OF DEGREES IN (9)	° ′
		X60	11	REPEAT (9)	
3	(2) X 60		12	NUMBER IN (10) X 3600	
4	NUMBER OF MINUTES IN (1)		13	(11) – (12)	
5	(3) + (4)		14	NUMBER OF TIMES 60 DIVIDES INTO (13) = NUMBER OF MINUTES IN (9)	′ ″
		X60	15	REPEAT (13)	
6	(5) X 60		16	NUMBER IN (14) X 60	
7	NUMBER OF SECONDS IN (1)		17	(15)-(16)=NUMBER OF SECONDS IN (9)	″
8	(6) + (7) ENTER IN (4) ON FRONT		18	(10) + (14) + (17)= CONVERGENCE (ENTER IN (23) ON FRONT)	° ′ ″

GIVEN:

UTM grid zone of area of operation.
UTM grid coordinates of station to nearest meter.
Latitude and longitude of station to nearest second or one-hundredth mil (DA Form 6-10, 6-10a, or 6-11).
A value of astronomic azimuth for each set of observations (DA Form 6-10, 6-10a, or 6-11).

GUIDE:

When using a mil-graduated instrument, - -

a. (1) through (5), (7) through (10), and (20) through (22) of computation are computed using hundredth-mil values.
b. (6) and (24) through (33) of computation are computed using tenth-mil values.

Compare (10) and (22) and, if they differ by more than 4 seconds or 0.02 mils, redetermine coordinates and recompute all computations.

LIMITATIONS:

This form should not be used when accuracies greater than third-order are required.

RESULTS:

A value of UTM grid azimuth from the mean values of astronomic azimuth and the grid convergence at the station.

FORMULAS:

UTM grid azimuth = Astronomic azimuth + convergence.
USING UTM GRID COORDINATES:
Convergence = $(XV)q - (XV\text{I})q^3$
(XV) = a variable function based on latitude of station (obtained from TM 6-300-19__, "Army Ephemeris for 19__").
q = 0.000 001 times the distance in meters from central meridian of UTM grid zone to station.
$(XV\text{I})q^3$ = second term of convergence computation (obtained from TM 6-300-19__, "Army Ephemeris for 19__").
USING GEOGRAPHIC COORDINATES:
Convergence = $(XII)p + (XIII)p^3$
(XII) = 10,000 times sine of latitude of station.
p = 0.0001 times distance in seconds or mils of arc from central meridian of UTM grid zone to station.
$(XIII)p^3$ = second term of convergence computation (obtained from TM 6-300-19__, "Army Ephemeris for 19__").

Figure 14-57. DA Form 6-20 (back).

conversion of seconds to degrees, minutes and seconds.

g. Guide. The guide on the back of the form includes limitations, results and formulas.

14–63. Example of Computing Convergence

a. Given Data.

(1) Station: TS 20.

(2) Latitude: 34°39′48″ N.

(3) Longitude: 98°24′18″W.

(4) Coordinates: (554460–3835590).

(5) Astronomic azimuth to mark: 4,318.63 mils.

b. Solution. See figures 14–56 and 14–57.

Section XI. SIMULTANEOUS OBSERVATIONS

14–64. Principles of Simultaneous Observations

a. Simultaneous observations of a celestial body provide a rapid method of transmitting direction over great distances without time-consuming computations. This method is ideally suited to the needs of the field artillery, since many units can be placed on common directional control in a very short period of time.

b. Because of the great distances of celestial bodies from the earth, the directions to a celestial body at any instant from two or more close points on the earth are approximately equal. The difference between the azimuths is primarily due to the fact that the azimuths are different points are measured with respect to different horizontal planes. This difference can be determined.

14–65. Procedures for Simultaneous Observations

a. Flank stations are established at points where azimuth is desired. A master station is established at a point from which the grid azimuth (an assumed azimuth may be used) to an azimuth mark is known or has been computed (fig 14–58). Both the bank and master stations should be points which are easily identified on a map and which provide the best possible communications.

b. An observing instrument is set up at the master station and oriented on the azimuth mark. An observing instrument is set up at each flank station and oriented on a reference mark to which the azimuth is desired (fig 14–59). A prominent celestial body is selected by the observer at the master station and is identified to the observer at each flank station. The observer at the master station must wear a lip or throat microphone so that he can transmit information at the same time he observes a celestial body. A headset, loudspeaker, or other device must be provided for the observer at each flank station so that he can hear instructions from the observer at the master station. When all stations are ready to observe, the master station observer announces READY, START TRACKING (countdown), TIP. The master station observer makes pointings on the sun or on a star. Each flank stations observer, if he is observing a star, places the vertical crosshair of his instrument on the star and keeps it there with the horizontal recording motion tangent screw. If he is observing the sun, he keeps the vertical crosshair tangent to one edge of the sun and approximately bisects the sun with the horizontal crosshair. The master stations observer announces TIP at the instant the star is at the intersection of the crosshairs or when the sun is tangent to both crosshairs. The master station observer records the readings on the horizontal and vertical scales. Each flank station observer records the reading on the horizontal scales. All observers then plunge their telescopes and repeat the tracking procedure. (When using the M2 aiming circle, the operator sights a second time on the body.) If the sun is being observed, the master station observer places the image on the sun in the diagonally opposite quadrant, and each flank station observer tracks with the vertical crosshair tangent to the edge of

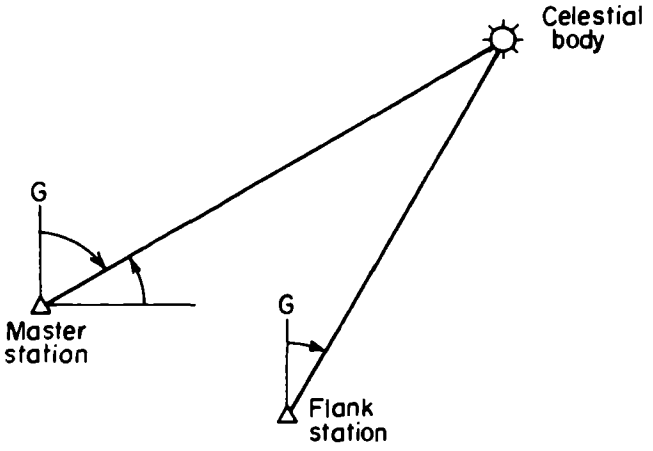


Figure 14–58. Simultaneous observations.

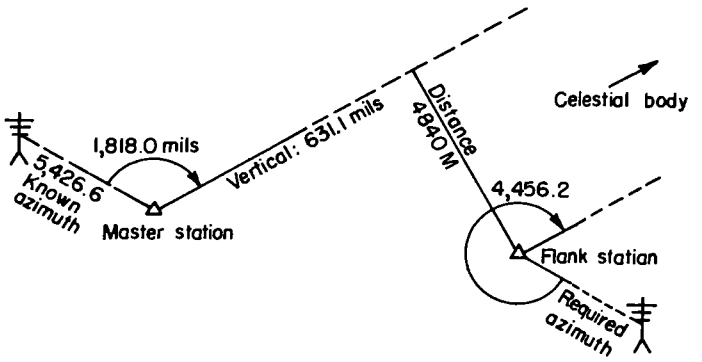


Figure 14–59. Relative locations of stations for simultaneous observations.

the sun opposite the edge used with the telescope direct. The master station observer announces TIP, and each observer records the appropriate scale reading as he did for the first pointing.

c. At the master station, the measured horizontal angle is added to the known azimuth to the mark to determine the azimuth to the sun. The grid coordinates, vertical angle to the sun, and the azimuth of the sun are transmitted to each flank station. The flank station operator plots on his chart a line representing the azimuth from the master station to the celestial body. From the flank station, a line is drawn perpendicular to the line representing the azimuth from the master station to the celestial body. The flank station observer then can determine the correction of the azimuth to the sun from the master station in order to determine the azimuth to the sun from the flank station. This correction is determined by using the correction nomograph in figure 14–60 or table 13 in the Army Ephemeris.

d. The nomograph consists of three columns. The left column is graduated in meters from 100 to 1,000 and represents the value of the length of the line (D) from the flank station to the plotted line, which represents the azimuth to the sun from the master station. The center column is the correction (C). It is graduated in seconds and mils from 0.5″ to 70″ and 0.003m̄ to 0.3m̄. The right column is graduated in degrees and mils from 10° to 65° and 180m̄ to 1,150m̄. It represents the vertical angle to the celestial body at the master station (H). To determine C, the values of D and H must be known and used as arguments in the nomograph. When the distance exceeds 1,000 meters, it is necessary to divide the distance by 10, 100, or 1,000 to obtain a value between 100 and 1,000. In such cases, the chart value of C must be multiplied by the same value by which the distance was divided. The value of H must be between 180 and 1,150 mils. If the flank station is to the left of the line from the master station to the celestial body, the sign of the correction is plus; if the flank station is to the right, the sign of the correction is minus.

e. When the azimuth to the sun from the flank station has been determined, the measured horizontal angle is subtracted. The result is the azimuth to the azimuth mark at the flank station.

14–66. Example of Transmission of Azimuth by Simultaneous Observations

a. Mean data from observations are as follows:
Master station:
Horizontal angle = 1,818.0 mils
Vertical angle = 631.1 mils
Flank station:
Horizontal angle = 4,456.2 mils

b. The grid azimuth to the mark at the master station is 5,428.6 mils. The grid azimuth to the body at the master station is 846.6 mils (5,428.6 mils + 1,818.0 mils).

c. The relative locations of stations are shown in figure 14–59.

d. The nomograph is entered by using the value of the mean vertical angle, 631.1 mils, and the distance 4,840 meters. The correction obtained from the nomograph is 0.056 mil (X 10), or 0.6 mil expressed to the nearest tenth of a mil. The value of the correction is applied to the grid azimuth from the master station to the body, and an azimuth of 846.0 mils is obtained. This is the grid azimuth from the flank station to the celestial body.

e. The correct grid azimuth from the flank station to the body is 846.0 mils. The mean observed horizontal angle at the flank station is 4,456.2 mils. The azimuth to the mark at the flank station is 846.0 + 6,400 — 4,456.2 = 2,789.8 mils.

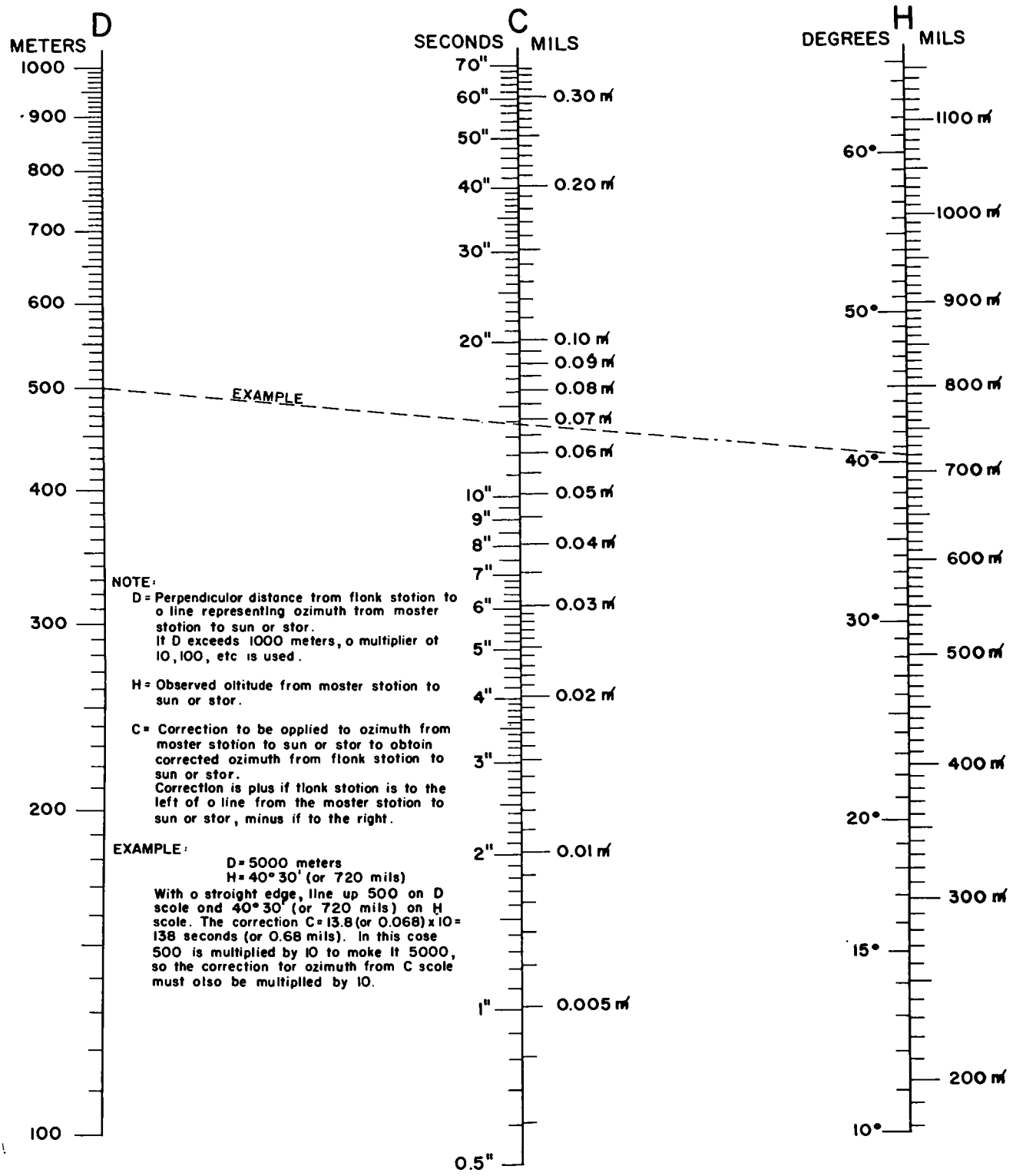


Figure 14-60. Correction nomograph.

CHAPTER 15
GYRO AZIMUTH SURVEYING INSTRUMENT

Section I. GENERAL

15–1. General

a. The artillery gyro azimuth surveying instrument (azimuth gyro) is a portable gyrocompass used to determine a true direction. With this instrument, a direction can be determined under conditions of poor visibility without lengthy computations and with an accuracy that is comparable to that of astronomic observations. This surveying instrument detects earth rotation. It consists of a high quality rate-measuring gyro together with the electronics necessary to provide a signal proportional to the space rate of rotation of the gyro about a known axis (fig 15–1). In operation, the gyro is placed in a fixed relationship to the earth; the direction of its sensitive (input) axis being referenced by the internal azimuth scales of the theodolite. The NULL METER shows whether or not the gyro is rotating about that axis. If it is, its direction on earth is changed until a null or "no rotation" position is reached. Thus repositioned the input axis must then be alined in a true east-west direction. This instrument is for use in latitudes between 60° north and 60° south of the equator.

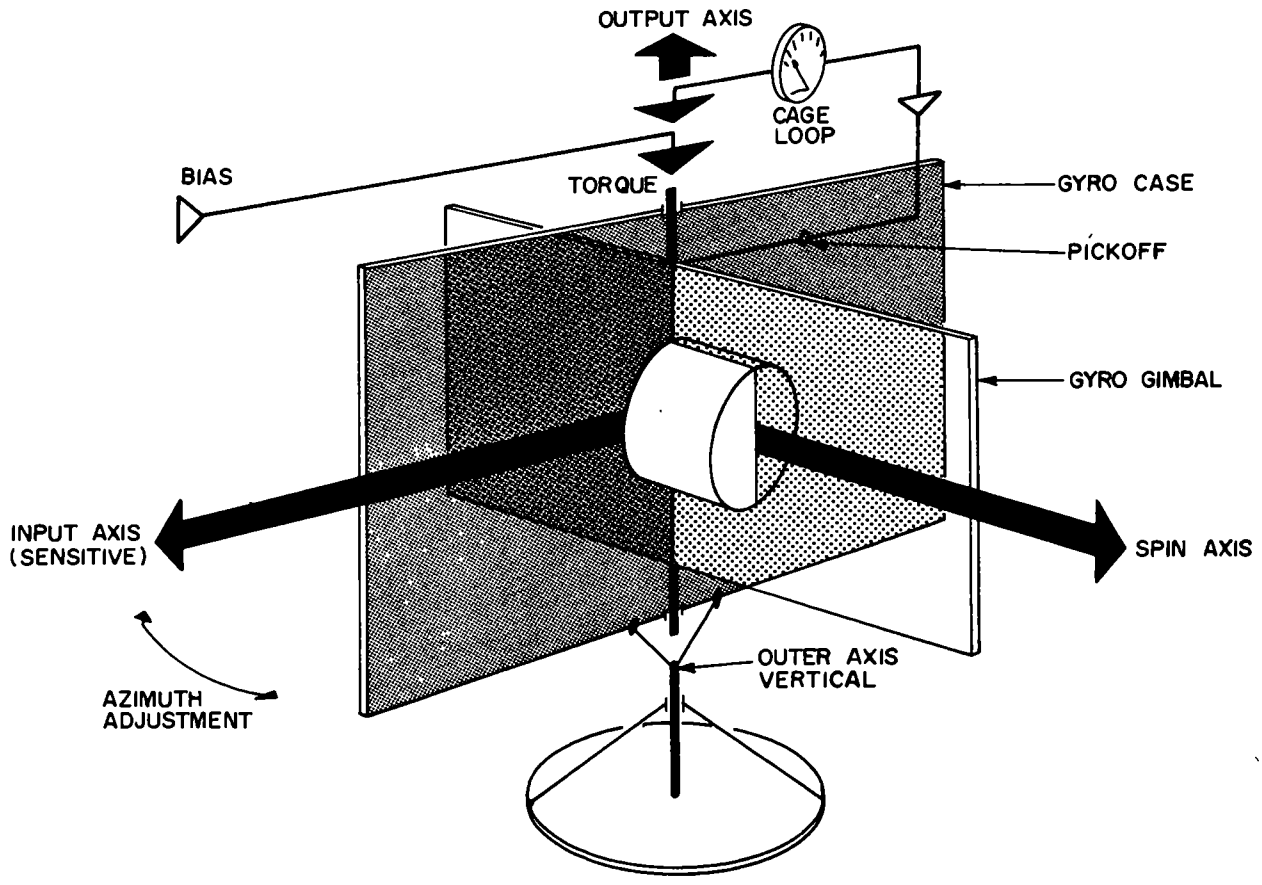


Figure 15–1. Axis system.

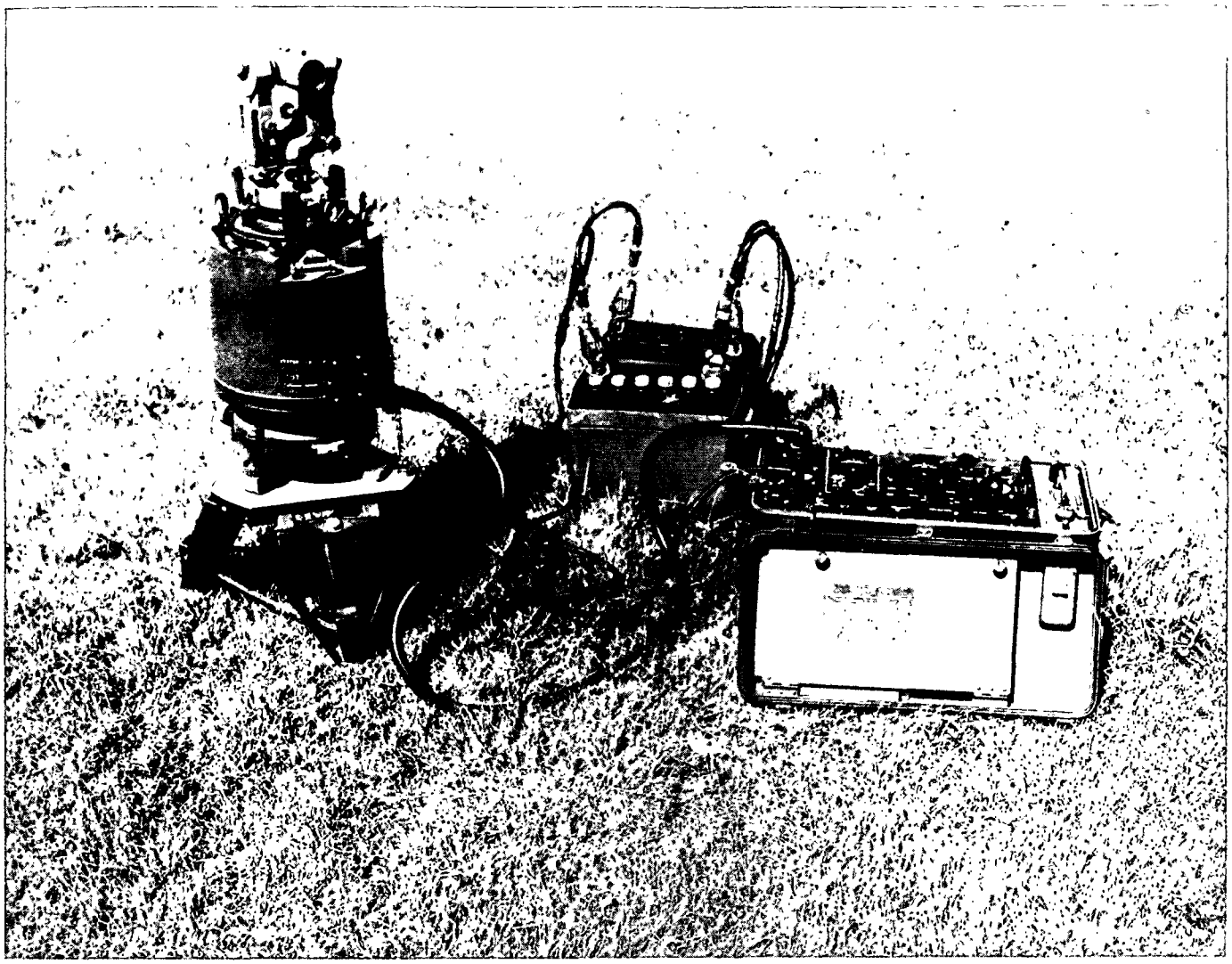


Figure 15–2. The artillery gyro azimuth surveying instrument.

b. The instrument is authorized for field artillery howitzer, gun and missile battalions; for the survey element in the headquarters battery of division artillery; and for the batteries of target acquisition battalions.

Note. There are two models of the Azimuth Gyro Surveying Instrument designated the ABLE (Autonetics Base Line Equipment) Model C2A and Model C2B. The two models are the same with the following exceptions:

(1) The model C2B has means to illuminate the theodolite scale by addition of a transformer, rheostat connector, and an external cable.

(2) The accessory equipment includes a collimating eyepiece for the theodolite.

(3) The gyro incorporates a flush-fill capability.

15–2. Description of Components

The components of the artillery azimuth gyro are as follows (fig 15–2):

a. Sensing Element. The sensing element consists of the gyroscope case and the 0.002-mil-graduated theodolite mounted on top of the case.

(1) The gyroscope case contains a highly sensitive single axis rate gyroscope. On the outside of the case are the leveling screws, leveling bubbles, an azimuth lock and vernier, and a digital counter to measure increments of sensing element azimuth changes.

(2) The 0.002-mil theodolite differs from the standard theodolite in that is is equipped with a special mounting device and the circle-setting knob is locked in position. When the theodolite is

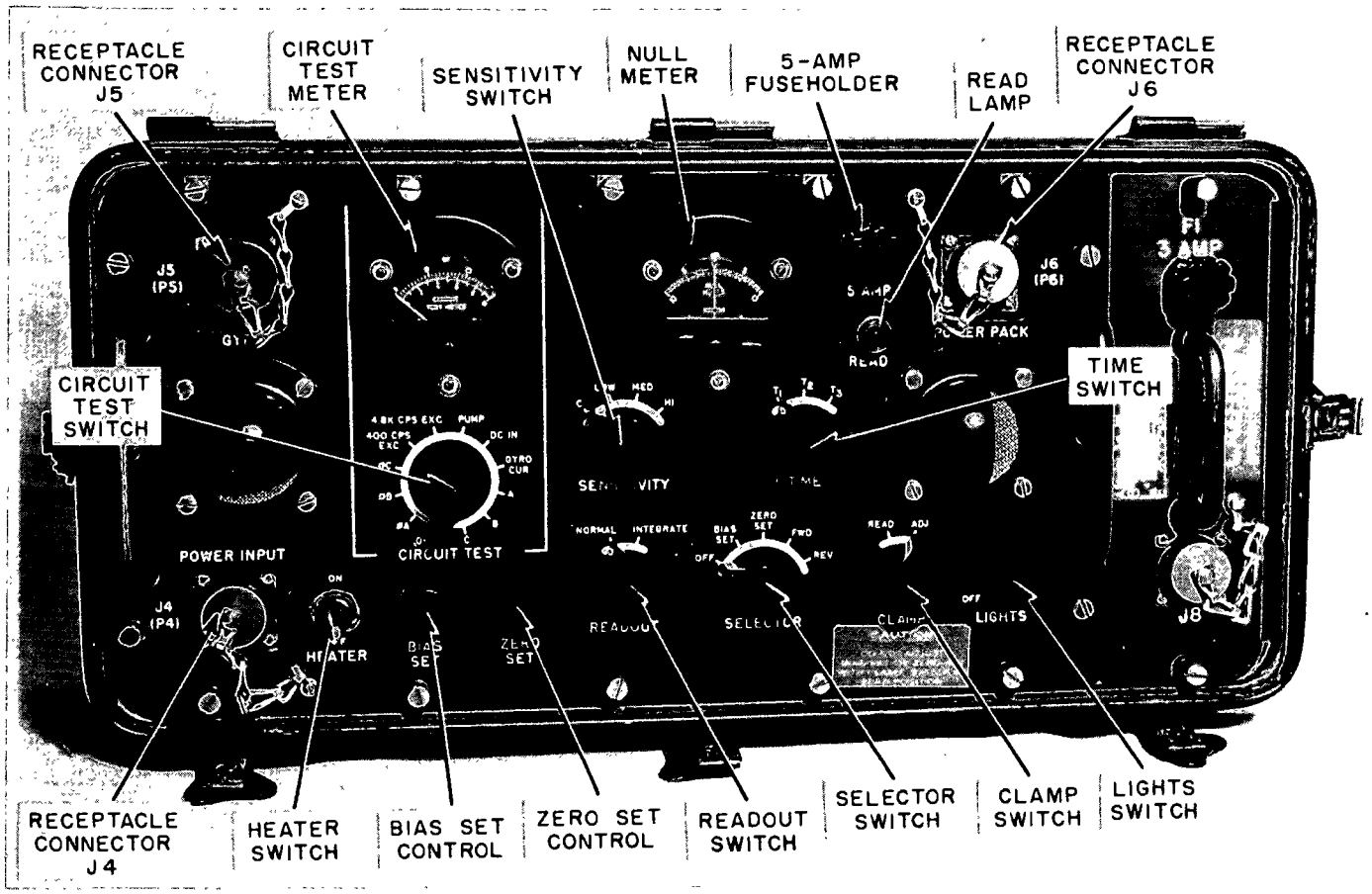


Figure 15–3. Control-indicator panel.

installed in the special mounting device, the horizontal circle of the theodolite is mechanically aligned with the gyroscope so that the line from 0 to 3,200 mils on the horizontal circle is in coincidence with the spin axis of the gyroscope.

b. Controlling Indicator. The control indicator is an electronic package which provides power to the gyro rotor, the heating elements, and the signals for measuring the amount and direction of the gyro misalinement. The control indicator panel (fig 15–3) provides the controls and indicators necessary for the operation and the directional alinement of the instrument. Receptacles are provided for cabling the control indicator to the power supply and to the sensing element. Located on the control panel are the following controls and indicators:

(1) *CIRCUIT TEST section.* The CIRCUIT TEST section is provided for checking the circuits and for troubleshooting. Before the system is operated, all the electrical circuits are tested to insure that electrical conditions are correct.

(2) *READ lamp.* The indicator READ lamp is located in the upper right part of the control panel. When lit, the READ lamp indicates that the CLAMP switch has been turned from the ADJ position to the READ position and that readings can be taken from the null meter. Brightness of the lamp can be controlled by rotating the button on the lampholder.

(3) *HEATER switch.* A two-position toggle switch is located in the lower left part of the control panel to actuate the heating elements contrained within the sensing element. The HEATEr toggle switch must be in the ON position whenever the surrounding temperature is +50° F or less.

(4) *BIAS SET control.* The BIAS SET control permits the adjustment of bias to the gyro output axis and thereby returns the null meter to a zero reading. The SELECTOR switch must be in the BIAS SET position while the adjustment is made.

(5) *ZERO SET control.* The ZERO SET con-

trol permits adjustment of the readout amplifier drift to zero. The SELECTOR switch must be in the ZERO SET position while the adjustment is made.

(6) *LIGHTS switch.* A rheostat-type switch is located in the lower right corner to turn the panel lights on or off and to control their intensity.

(7) *SELECTOR switch.* The SELECTOR switch is located in the lower central area of the control-indicator panel. It is used to turn the entire system on or off. In its BIAS SET position, the BIAS SET control can be adjusted to bias the gyro and to center the NULL METER. When in the ZERO SET position, the ZERO SET control can be adjusted to zero the amplifier drift and to center the NULL METER when in the FWD position, the gyro is operating in the normal circuit. When the switch is in REV, the rotation of the gyro rotor is reversed.

(8) *CLAMP switch.* A two-position switch is provided for the read and adjust modes. The CLAMP switch must be in the READ position when the NULL METER is to be read. When the orientation of the sensing element is to be changed, when the direction of the rotation of the rotor in the gyro is to be change, or when the BIAS SET or ZERO SET adjustments are being made, the CLAMP switch must be in the ADJ position.

(9) *READOUT switch.* The two positions of the READOUT switch are NORMAL and INTEGRATE. When the switch is in the NORMAL position a direct indication of the amount and direction of the gyro misalinement is reflected on the null meter; when the switch is in the INTEGRATE position, the integral of this value is reflected on the null meter.

(10) *SENSITIVITY switch.* The null meter pointer can be made more sensitive, or reactive, to electrical signals by moving the SENSITIVITY switch from LOW to MED or from MED to HI until the desired sensitivity is reached. The sensitivity changes by a factor of 2 from low to medium, and from medium to high. The C, or coarse, position is a very low sensitivity position which is used for making initial azimuth adjustments of the sensing element.

(11) *TIME switch.* The TIME switch provides three times—T1, T2, and T3—with periods of 30, 60, and 120 seconds, respectively, for null meter filter time (READOUT switch in NORMAL) or integration time (READOUT switch in INTEGRATE).

(12) *NULL METER.* The null meter is a dial-type meter which indicates, when centered, that the spin axis of the sensing element is accurately alined with the true north-south line.

c. Tripod. The tripod (fig 15–4) issued with the equipment is used with the sensing element and consists of three major parts—the tripod head with the housing for the tripod leg, a set of three wooden tripod legs, and a set of three short metal tripod legs. The two sets of tripod legs are interchangeable, and either set may be used with the tripod head. Each leg is retained in the housing by a single bolt. The short metal legs are recommended for greater rigidity and stability. The safety chain around the feet of the tripod legs must be secure each time the tripod is set up.

d. Carrying Case and Accessories. The carrying case is a heavy-gage drum-type container which affords protection against exterior abuse and provides maximum environmental protection for the sensing element during transit or storage. Six hook-type clamps secure the cover to the case, and a rubber gasket forms an airtight seal. A pressure relief valve facilitates removal of the airtight cover when internal and external pressures are unequal. An external electrical receptacle is provided on the side of the container for either 24-

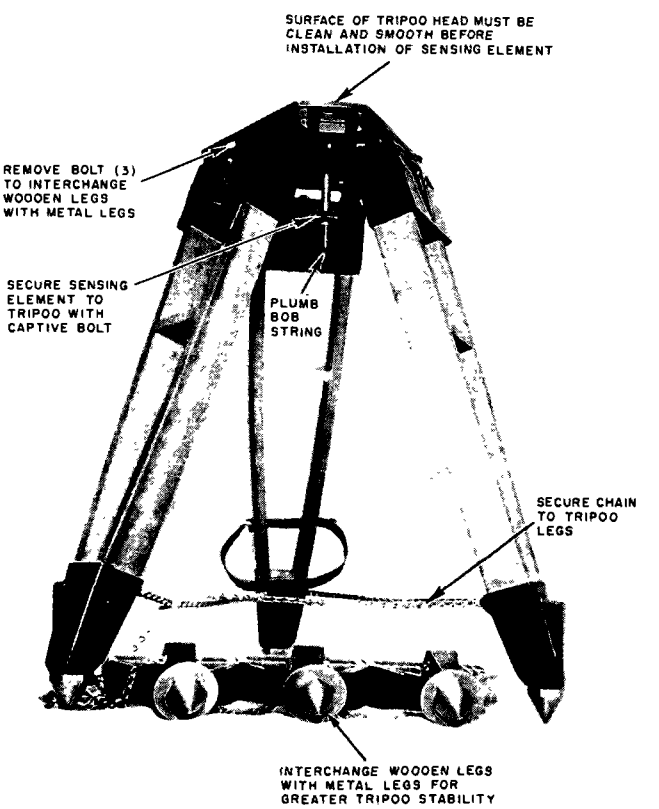


Figure 15–4. Tripod.

volt DC or 115-volt AC current that is used for heating the sensing element during movement or storage. Accessory equipment consists of three power cables, two adapters, two clips, the sensing element insulation cover, and technical manuals (fig 15–11 and 15–12).

15–3. Principles of Operation

The gyroscope of the azimuth gyro detects the earth's rotation. A bias adjustment is made to insure that the only torque (force) exerted on the gyroscope is the rotation of the earth. Through an electrical system, a signal is provided on the null meter that is proportional to the amount and direction of the misalinement of the gyro input axis with respect to the direction of the earth's rotation. The gyroscope is repositioned in azimuth until a null position on the meter is reached. When the gyro is so positioned with respect to the earth that the component of the earth's rotation rate on the input axis is zero, the null meter registers a null and the spin axis is alined in a true north-south direction. Since the line from 0 to 3200 mils on the horizontal circle of the theodolite is mechanically aligned with the spin axis of the gyroscope, the horizontal circle is oriented on true north. For any pointing now made with the theodolite, the horizontal circle reading is a direct readout of the true direction from the instrument to the sighted point. This true direction is then converted to a grid direction by applying the grid convergence.

Section II. OPERATION OF THE AZIMUTH GYRO

15–4. Selecting an Operating Site

Precautions must be taken to select a station on firm ground away from large trees and pedestrian or vehicular traffic. If both ends of a line for which the direction is to be established can be occupied, the equipment should be set up at the end with the least activity in the general area. The selected station must be at least 3 meters away from pedestrian traffic and at least 10 meters away from vehicular traffic. For best results, the system should always be protected from weather by a plywood shelter. Wind gusts will be sensed by the gyro and will cause erratic operation. Tree roots will carry the effect of wind into the ground near trees. Direct sun rays will cause erratic operation due to the unequal contraction and expansion of the various parts of the unit. The sensing element, the control indicator, and the 24-volt power supply must be shaded from the sun during operation when the ambient temperature is in excess of 75°.

15–5. Setting up the Instrument

a. Tripod. Open the legs until the tripod head is at the desired operating height and adjust the chain to secure the legs with a minimum of slack in the chain. Center the tripod over the station, and use foot pressure of at least 100 pounds to firmly embed the tripod legs in the ground. The bubble in the circular level vial should be approximately centered at the completion of this operation. For setups on reasonably flat terrain, detents in the hinges permit the legs to be positioned at identical angles.

Caution: **The chain must be secure on the legs to prevent inadvertent collapse of the tripod and severe damage to the sensing element.**

b. Sensing Element. Use extreme care when handling any part of this highly precise and sensitive instrument. When transporting the instrument, always store the items in their respective carrying cases. Secure the cases to the transport vehicle in such a way that they will not tip, slide, or leave the bed of the vehicle at any time (fig 15–5). If this precaution is not observed, the equipment may be damaged or misalined. If the sensing element secured within its carrying case is subjected to a drop of 4 inches or more, the alinement may be affected. Always keep the sensing element carrying case vertical. Always life the sensing element by the two handles provided to prevent damage or misalinement. Do not attempt to shift or move the tripod with the sensing element attached. If any type of rough handling is observed or suspected, the alinement of the sensing element must be verified.

To prepare the sensing element for operation—

(1) Release the holddown clamps and remove the theodolite, still attached to the carrying plate. Set the theodolite in a safe place (For model C2A).

(2) Check to see that the mating surface of the sensing element and the tripod head are clean. Place the sensing element with its leveling screws over the corners of the tripod, and position the tripod fixing screw so that it can be screwed into the base plate of the sensing element. Tighten the

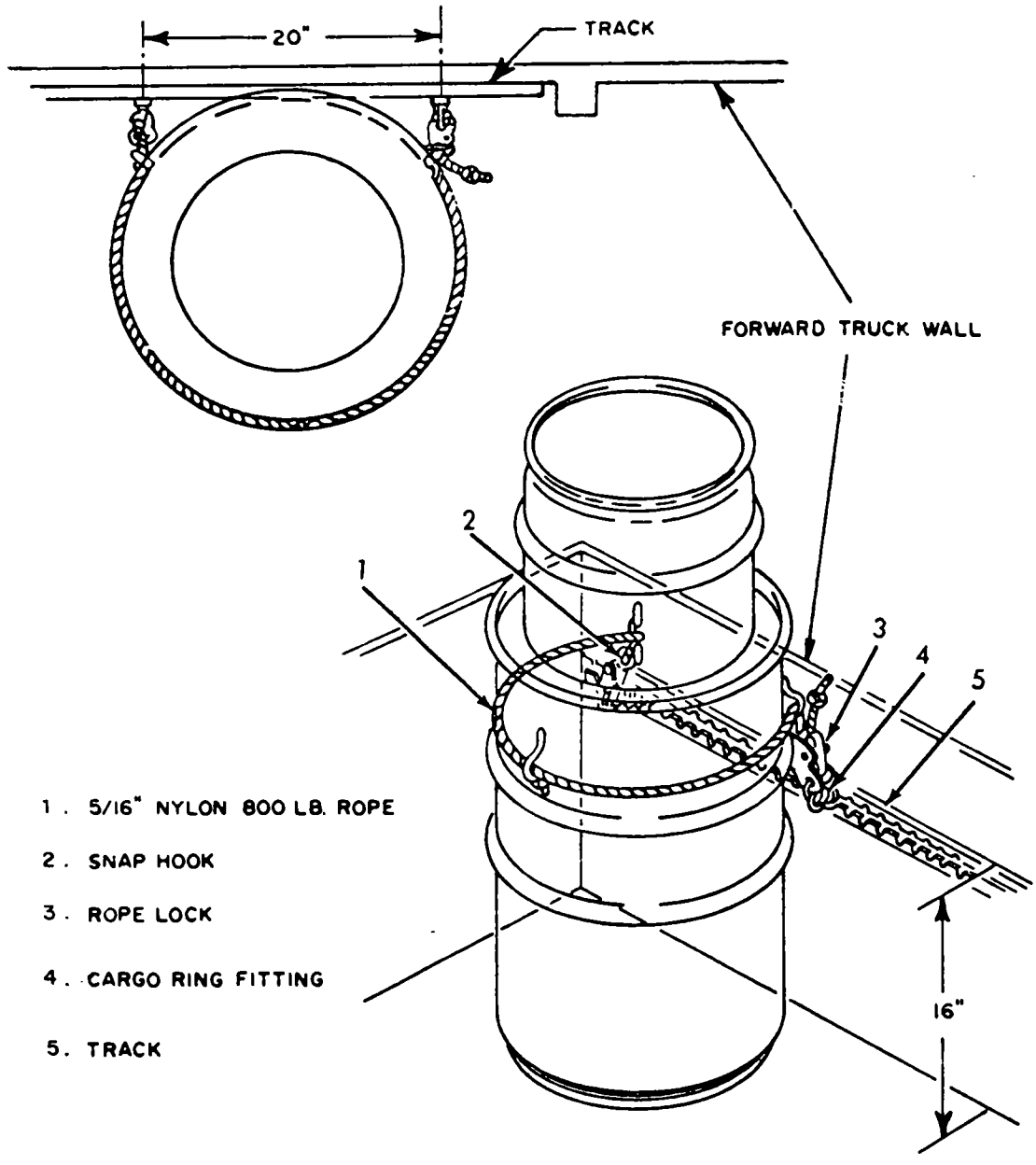


Figure 15–5. Securing for transporting.

fixing screw to secure the sensing element to the tripod.

(3) Install the plumb bob on the hook of the fixing screw, and plumb the instrument exactly over the station.

(4) Remove the dust cap from the electrical connector J1–P. On the model C2B, remove the additional dust cap from electrical connector J5–S.

(5) Wipe the mating surfaces of the theodolite and sensing element.

(6) Remove the theodolite from its carrying plate and attach it to the sensing element.

c. Leveling the sensing element. To level the Sensing Element—

(1) Release the azimuth lock by turning the spanner, counterclockwise (no more than one turn) so that the sensing element may be rotated freely by hand.

(2) Place one hand on each side of the sensing element, or one hand on each handle, and gently rotate the sensing element in azimuth until one of the index arrows at the bottom of the sensing element lines up with an index arrow on the base.

(3) Two leveling screws and a pivot point are

located on the base of the sensing element in a tribrach arrangement. When the index arrows are in alinement ((2) above), the axis of one level bubble is parallel to the line through the pivot point and one leveling screws, while the axis, of the second level bubble is parallel to the line from the second leveling screws. Adjust the leveling screws until the level bubbles are centered.

(4) Rotate the sensing element 3,200 mils in azimuth until the index arrows again line up. If the level bubbles are in correct adjustment, the bubbles will remain centered. If the bubbles do not remain centered the appropriate leveling screws must be adjusted to correct for one-half the indicated misalinement.

(5) Rotate the sensing element to the first index position. The level bubbles should read the same as in (4) above.

(6) Repeat the leveling procedure ((2) through (5) above), using the split bubble levels.

(7) Tighten the azimuth lock on the sensing element.

(8) Loosen the horizontal circle clamp on the .002 mil theodolite, and rotate the alidade until the axis of the plate level vial is parallel to an imaginary line formed by one of the leveling screws on the theodolite mounting bracket and the bracket pivot point. Note the position of the plate level bubble. Rotate the alidade 3,200 mils, and again note the position of the bubble. Repeat this operation, using the second leveling screw. If the various positions of the bubble are the same within plus or minus one-half division, the theodolite and sensing axis are parallel; if not, the theodolite must be leveled using the same procedure as for the sensing element. A special tool is available in the carrying case for rotating the leveling screws on the mounting bracket.

(9) Release the sensing element azimuth lock, and rotate the sensing element until the mirror window points generally west.

(10) Secure the sensing element azimuth lock, and leave the theodolite horizontal circle clamp free.

d. Connecting the Power Cables. Before connecting the power cables (figs 15–6 and 15–7) for operation of the equipment, set the switches on the control indicator panel to the following positions:

Switch	*Position*
CIRCUIT TEST	OFF
HEATER	OFF
SELECTOR	OFF
SENSITIVITY	HI
READOUT	NORMAL
TIME	T1
CLAMP	ADJ

(1) To connect the cables for DC operation—

(*a*) Select either of the two No 5 branched cables as applicable.

(*b*) Remove dust caps from No 5 cable connector and from power input receptacle J4 and connect cable to control-indicator.

(*c*) Observe polarity (P3-red positive and P2-black negative) of the branched end of cable No 5, and plug into the appropriate battery clips to the proper battery terminals.

(*d*) Use cable No 2 with battery clip adapters to connect two 12-volt batteries in series to provide a 24-volt source.

(*e*) Remove dust caps from cable No 4 and receptacles J5 and J1–P. Install No 4 cable connector marked P5 in receptacle J5 and install other end in receptacle J1–P.

Caution: **Cable No 4 must be positioned to minimize the forces transmitted to the sensing element. Sharp bends in the vicinity of the sensing element must be avoided, and the cable must not be allowed to touch the wind shelter being used.**

Note. Cable No 4 for later models of C2A and for model C2B is supplied in an 8-foot length.

(*f*) When utilizing a vehicular source of 24-volt DC power, connect cable No 3 to the positive end of cable No 5 and to the mating connector on the vehicle. The ground connection is made to the vehicle through a battery clip adapter attached to the negative end of cable No 5.

(*g*) For model C2A, attach the theodolite electrical lead between the theodolite battery box and the theodolite electrical connector.

(*h*) For the model 2CB, attach the 6 inch cable No 7 to connector J5–S on the sensing element and to the theodolite electrical connector (fig 15–8).

(2) To connect the cables for AC operation—

(*a*) Remove the 24-volt DC power-pack from the control-indicator case. In use, this power-pack heats, and it must be removed to avoid unequal heating of elements in the control-indicator.

(*b*) Remove dust cap from connector of No 1 cable and from control-indicator receptacle J4. Install cable connector in receptacle J4 and attach other end to AC power source.

(*c*) Remove dust caps from No 6 cable, +24-volt supply receptacle J8 and control-indicator receptacle J6. Install cable connector marked

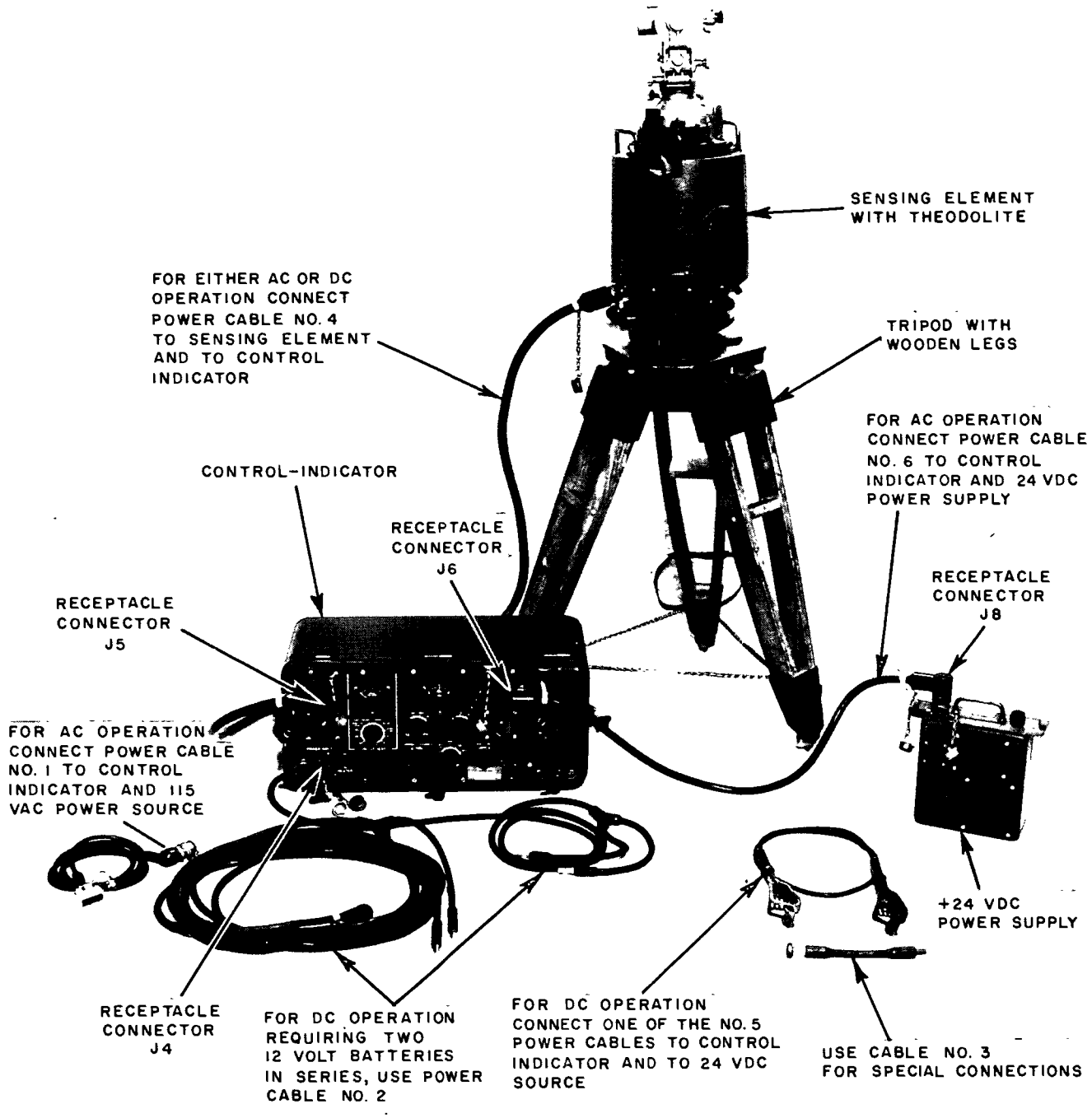


Figure 15–6. Surveying instrument connections for AC and DC operations, Model C2A.

P8 in receptacle J8 and install other connector in receptacle J6.

(*d*) Install No 4 cable as outlined in (1) (*c*) above.

(*e*) For model C2A, install the theodolite electrical lead as outlined in (1) (*g*) above.

(*f*) For model C2B, install No 7 cable as outlined in (1) (*h*) above.

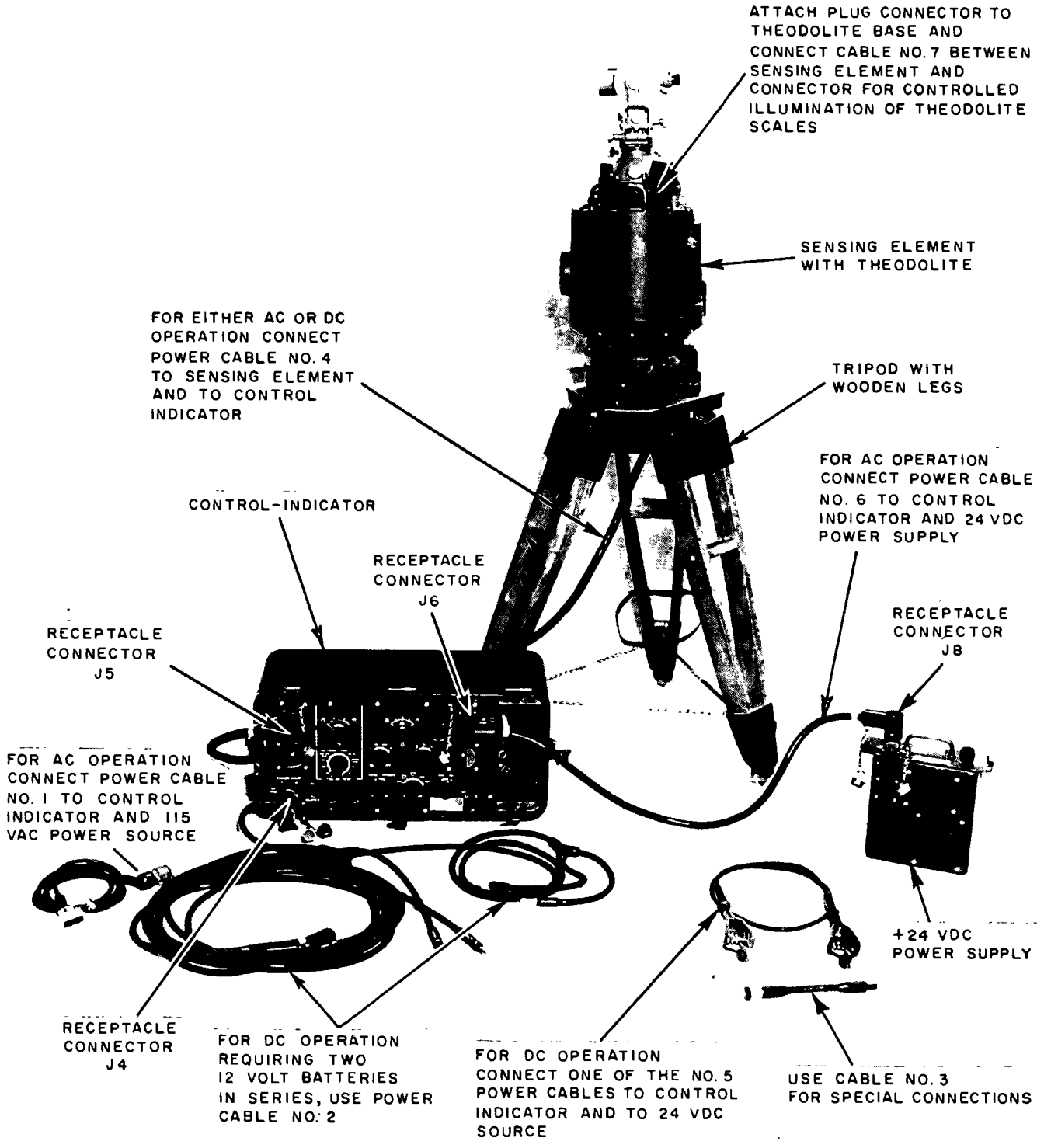


Figure 15-7. Surveying instrument connections for AC and DC operations, Model C2B.

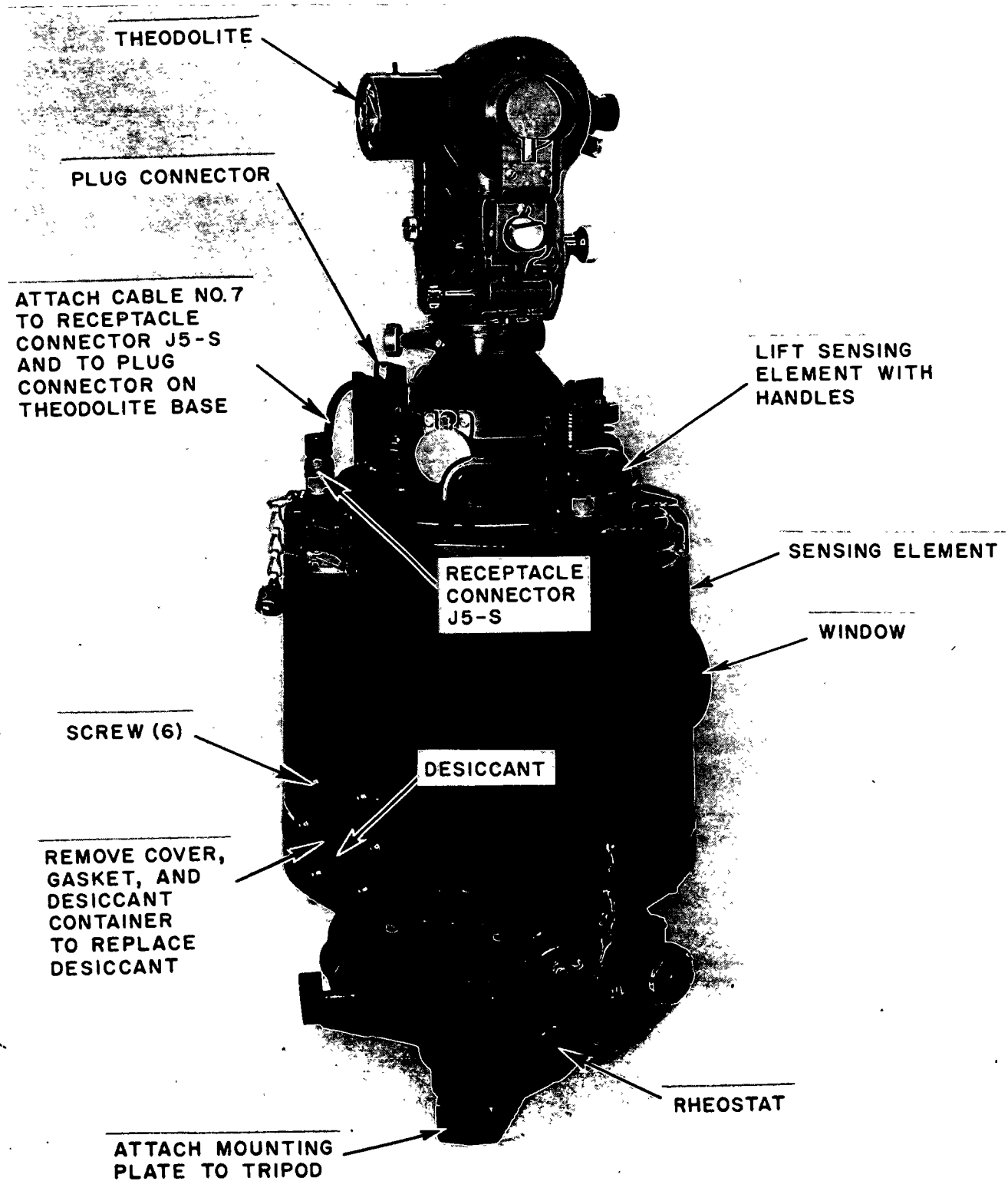


Figure 15-8. Sensing element with theodolite, Model C2B.

Section III. USE, CARE, AND MAINTENANCE OF THE AZIMUTH GRYO

15–6. Azimuth Measurement Procedures

To measure an azimuth, after the azimuth gyro has been set up and connected to a power source as described in paragraph 15–5, perform the following steps in the sequence shown:

Note. In all phases of the operation of the azimuth gyro, the indicator or the NULL meter must never be allowed to touch the stops at the ends of the meter scales. If the NULL meter indicator appears to be going to a full scale reading switch the CLAMP switch to ADJ and make the appropriate adjustment before reading the NULL meter again.

a. Circuit testing.

(1) Turn the SELECTOR switch to BIAS SET.

(2) Check to see whether the fan is circulating air by placing a hand over the air exhaust duct located above the CLAMP switch. If air is not circulating, turn the SELECTOR switch OFF and recheck all connections. If the connections are good and air still does not circulate, turn the system in for repairs.

(3) Turn the LIGHTS switch to ON (night operation only).

(4) Turn the CIRCUIT TEST switch through positions ØA, ØB, ØC, 400 CPS EXC, 4.8K CPS EXC, PUMP, and DC IN, noting the reading on the appropriate scale of the circuit test meter. For AC operation, the readings must lie in the range shown on the circuit test panel on the inside cover of the control indicator. When batteries are used, the readings should be the same as for AC operation except that the reading for the pump should be 5–8.

(5) Place the CIRCUIT TEST swtich in the GYRO-CUR position. The reading will be zero.

(6) Turn HEATER switch on ON if the ambient temperature is less than +50°F.

b. Bias Set Adjustment.

(1) Turn the CLAMP switch to READ. Check to insure that the READ lamp comes on.

(2) Observe the position of the indicator on the NULL meter. Turn the CLAMP switch to ADJ.

(3) Turn the BIAS set control in the appropriate direction to zero the NULL meter needle.

(4) Turn the CLAMP switch to READ. Observe the position of the indicator of the NULL meter.

(5) Turn the CLAMP switch to ADJ. If necessary, continue to adjust the BIAS set control until a zero reading is obtained.

c. Zero Set Adjustment.

(1) Turn the SELECTOR switch to ZERO SET.

(2) Turn the CLAMP switch to READ. Observe the position of the indicator on the NULL meter.

(3) Turn the CLAMP switch to ADJ.

(4) Turn the ZERO set control in the appropriate direction to zero the null meter needle.

(5) Turn the CLAMP switch to READ. Observe the position of the indicator of the null meter needle.

(6) Turn the CLAMP switch to ADJ. If necessary, continue to adjust the ZERO SET control unit until a zero reading is obtained. Turn the CLAMP switch to ADJ.

(7) Turn the READOUT switch to INTEGRATE.

(8) Turn the CLAMP switch to READ.

(9) Observe the position of the indicator on the NULL meter when the READ lamp comes on (about 30 seconds). The indicator should be within 0.25 unit of zero. If not, repeat (1) through (8) above.

(10) Turn the CLAMP switch to ADJ.

d. Final Bias Adjustment.

(1) Turn the READOUT switch to NORMAL.

(2) Turn the SELECTOR switch to BIAS SET.

(3) Turn the CLAMP switch to READ.

(4) Observe the position of the indicator or the NULL meter when the READ lamp comes on. The indicator should be within 0.5 unit of zero. If it is not, turn the CLAMP switch to ADJ and turn the BIAS SET control in the appropriate direction to zero the NULL meter needle. Continue the adjustment until a zero reading is obtained. If an adjustment is made, repeat *b*(5) and *d*(1) and through (4) above.

(5) Turn the CLAMP switch to ADJ.

e. Alinement Procedure.

(1) Release the fast motion azimuth lock on the sensing element.

(2) Rotate the sensing element gently by hand until the mirror window of the sensing element points generally west or until the reading on the theodolite is the approximate azimuth to the azimuth mark.

(3) Set the digital counter of the azimuth

slow motion on the sensing element to 500 (center of 400–600 counter units).

(4) Turn the SELECTOR switch to REV.

(5) Wait 90 seconds for the gyroscope to reach synchronous speed. Synchronous speed is indicated by an abrupt drop in the gyro current on the circuit test meter. Then turn the SELECTOR switch to FWD.

(6) Check the gyro current on the circuit test meter.

(7) Turn the SENSITIVITY switch to C.

(8) Turn the CLAMP switch to READ. After a pause, turn the CLAMP switch to ADJ and then to READ. Observe the direction and reading on the null meter. If the indicator rests at a position more than one unit from zero, turn the CLAMP switch to ADJ and slowly turn the sensing element in small increments in the appropriate direction, using the two handles.

(9) Repeat (8) above until the null meter indicator is within one unit of zero.

(10) Turn the CLAMP switch to ADJ.

(11) Lock the fast motion azimuth lock on sensing element.

(12) Turn the SENSITIVITY switch to LOW.

(13) Turn the CLAMP switch to READ and observe the direction and reading on the null meter.

(14) Turn the CLAMP switch to ADJ and turn the digital counter knob in the appropriate direction for the proper amount which is determined as follows: One unit on the null meter is equal to a change of 30 units on the digital counter. For example, if the indicator on the null meter reads four units to the left of zero, the digital counter knob must be turned to the right to bring the indicator to zero. In this case, the product of 30 x 4 is subtracted from the digital counter reading of 5000, making the digital counter read 4880. Repeat this step until the indicator on the null meter lies within one unit of zero.

Note. If an azimuth correct to 1 mil is desired, achieve null, skip (15) through (21) below, and proceed with (22) below.

(15) Turn the CLAMP switch to ADJ.

(16) Turn the SENSITIVITY switch to MED.

(17) Turn the CLAMP switch to READ and observe the direction and reading on the null meter. If the reading is not zero, turn the CLAMP switch to ADJ and turn the sensing element in the appropriate direction for the proper amount. At this sensitivity setting, 1 unit on the null meter is equal to 15 units on the digital counter. Turn the CLAMP switch to READ; if the reading on the null meter is not zero, repeat this step. When the reading is zero, proceed.

Note. If an azimuth correct to 0.3 mil is desired, skip (18) through (21) below, and proceed with (22) below. For azimuth correct to 0.1 mil or 0.15 mil, proceed with (18) below.

(18) Turn the CLAMP switch to ADJ.

(19) Turn the SENSITIVITY switch to HI.

(20) Turn the CLAMP switch to READ and observe the direction and reading on the null meter. If the reading is not zero, turn the CLAMP switch to ADJ and turn the sensing element in the appropriate direction for the proper amount. At this sensitivity setting, one unit on the null meter is equal to a change of seven units on the digital counter. Turn the CLAMP switch to READ; if the reading on the null meter is not zero, repeat this step. When the reading is zero proceed.

(21) Turn the CLAMP switch to ADJ.

(22) Turn the SELECTOR switch to REV.

(23) Observe the azimuth mark with the theodolite in the direct position and then with the theodolite in the reverse position. Record and mean the readings (para 15–7).

(24) Turn the SENSITIVITY switch to LOW.

(25) Wait 5 minutes after gyro has gone into synchronization.

(26) Turn the CLAMP switch to READ.

(27) Repeat (13) through (23); (13) through (27) comprise one set of readings for azimuth determination.

f. Turning System Off.

(1) Turn the CLAMP switch to ADJ.

(2) Turn CIRCUIT TEST switch to OFF.

(3) Turn HEATER switch to OFF.

(4) Turn SENSITIVITY switch to HI.

(5) Turn READOUT switch to NORMAL.

(6) Turn TIME switch to T1.

(7) Change the setting of the selector switch from FWD to REV or from REV to FWD, depending on the initial setting, for 45 seconds and then to OFF.

(8) Disconnect all cables. Disconnect the power source cable first.

Note. Instructions in (7) above will reverse phase rotation of power input to the gyro and will bring the gyro rotor nearly to a standstill. Placing the selector switch to OFF will cut off all remaining power to the gyro.

(9) Do not remove the sensing element from the tripod until the gyro has completely stopped. Listen with an ear on the sensing element case to detect when the gyro has stopped.

15–7. Recording

a. After the azimuth gyro has been oriented (para 15–6*e*(23)), readout of direction is accomplished by taking one position with the theodolite to a desired mark or reference point. These readings are recorded in the field notebook and meaned, giving a direction to the reference point with the gyro rotating in one direction. The SELECTOR switch is then turn to the REV position and the instrument is again oriented (para 15–6*e*(24)–(27)). Readout of direction is again accomplsihed by taking one position with the theodolite to the same reference point. These readings are recorded and meaned, giving a direction to the reference point with the gyro rotating in the opposite direction. The mean of the directions determined with the gyro in forward and reverse rotation completes one set of readings.

EXAMPLE:

FWD reading:	D6011.111	= 6011.111
	R2811.121	= 6011.121
Total		12022.232

Mean FWD reading = 12,022.232 ÷ 2 = 6011.116

REV reading:	D6011.333	= 6011.333
	R2811.347	= 6011.347
Total		12022.680

Mean REV reading = 12022.680 ÷ 2 = 6011.340
Mean REV reading = 6011.340
Mean FWD reading − 6011.116
12022.456
Mean Azimuth = 12022.456 ÷ 2 = 6011.228

b. The mean true azimuth determined in *a* above is then converted to a grid azimuth by applying the covergence.

c. The following specifications must be met to determine an azimuth to the required accuracy with the azimuth gyro.

(1) For 1 mil accuracy, take two sets of readings with the SENSITIVITY switch in the LOW position. The sets must agree within 2 mils.

(2) For 0.3 mil accuracy (fifth-order astronomic), take three sets of readings with the SENSITIVITY switch in the MED position. The sets must agree within 0.8 mil of the man. At least two sets of readings must be used to determine the final mean azimuth.

(3) For fourth-order or higher accuracy azimuths, the effect of latitude cannot be ignored. To determine the number of sets required to obtain a 95 percent assurance of a particular accuracy, use the table in figure 15–9. Enter the appropriate latitude column, move down the column to the desired accuracy, and read the number of required sets from the column marked "N". For example, to obtain a 95 percent assurance of an accuracy of 0.15 mil at Fort Sill (latitude 35°), enter the column, move down the column to 0.146, and read the number of required sets from column N. The number of required sets in this case is seven. To obtain the same accuracy in Maine (latitude 45°) enter the 45° column, move down the column to 0.150, and read the number of required sets from column N. In this case, the number is nine. It should be noted that the figures in the table represent 95 percent assurance, which allows for about three probable errors. If a lower assurance can be tolerated, a fewer number so sets will be required. Each set used must agree with the mean of all sets within some amount (called the rejection limit) which varies with the latitude. The rejection limit is listed on the bottom of the table for each latitude. After the obviously bad sets are rejected, a first mean is taken and those sets which differ from this mean by more than the rejection limit are discarded. A final mean is taken of the remaining sets. The 95 percent assured accuracy of this mean is the value opposite "N" equal to the required sets in the column corresponding to the latitude of the station.

d. Units that are issued an azimuth gyro should operate the instrument at least once each month. After an azimuth gyro is obtained, an astronomic azimuth should be observed with the theodolite mounted on the azimuth gyro orienter. An initial set of 10 gyro and astronomic observations should adequately determine the instrument error. A record should be kept of all gyro azimuths which provide a comparison to astronomic azimuths. This record is used to determine the instrument correction. The record is kept on DA Form 5–72. A separate record is kept for each azimuth gyro. The cover and the first page of the record should completely identify the instrument. Figure 15–10 shows a sample record. The entries made in the 12 columns of the open double page on DA Form 5–72, as shown in the sample, are explained in (1) through (12) below.

(1) The date and hour of the observations are entered in the *date-time column* (column 1).

(2) The name of the station over which the instrument is set up is entered in the *sta. column* (column 2).

ACCURACY FIGURES IN MILS FOR THE MEAN OF N AZIMUTH SETS
BASED ON 95 PERCENT ASSURANCE

LATITUDE IN DEGREES

N	0	5	10	15	20	25	30	35	40	45	50	55	60
1	0.279	0.280	0.284	0.292	0.302	0.315	0.332	0.355	0.384	0.420	0.467	0.530	0.613
2	0.200	0.202	0.204	0.209	0.216	0.226	0.239	0.255	0.275	0.301	0.335	0.378	0.438
3	0.166	0.167	0.169	0.173	0.179	0.188	0.198	0.212	0.228	0.249	0.277	0.313	0.362
4	0.146	0.147	0.149	0.152	0.158	0.164	0.174	0.185	0.200	0.218	0.243	0.275	0.318
5	0.132	0.133	0.135	0.139	0.143	0.149	0.158	0.168	0.181	0.198	0.220	0.249	0.287
6	0.122	0.123	0.125	0.128	0.133	0.138	0.146	0.155	0.168	0.183	0.204	0.230	0.266
7	0.115	0.116	0.117	0.120	0.124	0.130	0.137	0.146	0.157	0.172	0.191	0.216	0.249
8	0.108	0.109	0.110	0.112	0.116	0.121	0.128	0.136	0.147	0.161	0.178	0.202	0.233
9	0.101	0.102	0.103	0.105	0.109	0.114	0.120	0.128	0.138	0.150	0.167	0.188	0.217
10	0.096	0.096	0.097	0.099	0.103	0.107	0.113	0.121	0.130	0.142	0.157	0.178	0.206
12	0.088	0.088	0.089	0.091	0.094	0.098	0.103	0.110	0.119	0.130	0.144	0.162	0.187
14	0.082	0.082	0.083	0.085	0.088	0.092	0.097	0.102	0.110	0.121	0.134	0.151	0.173
16	0.077	0.077	0.078	0.080	0.083	0.086	0.091	0.097	0.104	0.114	0.126	0.142	0.164
18	0.073	0.074	0.075	0.076	0.079	0.082	0.087	0.092	0.100	0.108	0.120	0.135	0.156
20	0.071	0.071	0.072	0.073	0.076	0.079	0.083	0.089	0.095	0.104	0.115	0.130	0.150
30	0.062	0.062	0.063	0.064	0.066	0.069	0.072	0.077	0.082	0.090	0.100	0.112	0.130
40	0.057	0.057	0.058	0.059	0.061	0.063	0.067	0.071	0.076	0.083	0.092	0.103	0.119
Rejection Limit	0.42	0.42	0.43	0.44	0.45	0.47	0.50	0.53	0.58	0.63	0.70	0.79	0.92

EXAMPLE: For a desired accuracy of 0.12 mils at 35 degrees latitude, it is necessary to take a minimum of ten azimuth sets. The rejection limit for 35 degree latitude would be 0.53 mils.

Figure 15-9. Azimuth gyro accuracy table.

(3) The name of the station used as an azimuth mark is entered in the *az. mk. column* (column 3).

(4) The azimuth of the observed line if known to a higher degree of accuracy than can be determined by artillery astronomic observations is entered in the known *grid azimuth* column (column 4).

(5) The grid azimuth as determined by the azimuth gyro is entered in the computed *grid azimuth column* (column 5). The gyro correction from column 11 and the convergence from column 6 are applied to the observed gyro azimuth to obtain the computed grid azimuth. A comparison may be made here as a check during training.

(6) The grid convergence is entered in the C column (column 6). The convergence must be computed or scaled from a map.

(7) The astronomic azimuth computed from the observations is entered in the *astro azimuth column* (column 7).

(8) The azimuth determined from one set of gyro observations is entered in the *gyro azimuth column* (column 8).

(9) The gyro correction is entered in the *gyro, corr. column* (column 9). The correction is obtained by subtracting the gyro azimuth in column 8 from the astronomic azimuth in column 7.

(10) The total of the entries in column 9 is entered in the *total column* (column (10)). The entry on each line of column 10 is the sum of the gyro correction on that line and the total on the preceding line.

(11) The mean correction is entered in the *mean corr column* (column (11)). The mean correction is obtained by dividing the number in column 10 by the number of entries included in the total.

(12) The weather, the initials of the gyro operator, and any other data which might affect the accuracy of the result are entered in the *remarks column* (column 12).

e. If for any reason, such as cloud cover, an astronomic azimuth cannot be observed and a reliable grid azimuth is available for the observed line, the gyro azimuth can be compared with the grid azimuth. This is done by applying the convergence, with sign reversed to the grid azimuth to obtain a true azimuth. The result is entered in the *astro azimuth column* and the value is inclosed in brackets to indicate that it is computed. The

INSTRUMENT : ABLE ORIENTOR #11

DESIGNATION _____ DATE _____ 19____

DATE / TIME	STA	AZ MK	KNOWN GRID AZIMUTH	COMPUTED GRID AZIMUTH	C	ASTRO AZIMUTH	GYRO AZIMUTH	GYRO CORR	TOTAL	MEAN CORR	REMARKS
6 JAN 64 0810	UNION	ART	3811.210	3811.210	-6.01	3817.220	3817.223	-.003	-.003	-.003	COLD; DAMP ZAD
16 JAN 64 0945	O'NEIL	CHIEF	4926.824	4926.823	-6.01	4932.833	4932.839	-.006	-.009	-.004	COLD ZOP
	TRANSPORTED 25 MILES OVER					SMOOTH ROAD					
16 JAN 64 1923	PARK	HOUSE	3380.761	3380.761	-6.01	3386.771	3386.783	-.012	-.021	-.007	COLD ZOP
20 JAN 64 1100	HERB	MAC	5572.222	5572.223	-6.01	5578.233	5578.865	-.008	-.029	-.007	COLD ZOP
22 JAN 64 1722	X-RAY	KETCH	2372.851	2372.849	-6.01	2378.859	2378.899	-.006	-.035	-.007	COLD ZOP
27 JAN 64 1815	QUEEN	WOLF	718.830	718.831	-6.01	724.841	724.853	-.012	-.047	-.008	COLD ZAD
	SEVERE COLD (MINUS					50°F) 2 DAYS					
30 JAN 64 0830	PARK	ROCKY	1011.183	1011.183	-6.01	1017.193	1017.199	-.006	-.053	-.008	COLD ZAD
3 FEB 64 0830	ZORN	ZILCH	1409.606	1409.605	-6.01	1415.615	1415.618	-.003	-.056	-.007	COLD ZOP

Figure 15-10. Sample field notes for an azimuth gyro.

other values for entry on DA Form 5-72 are b-tained in the same manner as when an astronomic azimuth is used for comparison. All events which might affect the accuracy or gyro correction of the instrument should be written boldly accorss the double page. If it is certain that the accuracy is affected, a new series of totals should be started. If it is probable that the gyro correction is not affected, the series may be continued but the survey officer should watch the corrections carefully to determine if a change in the correction occurs. Examples of events which should be entered as follows:

(1) Transported 25 miles over smooth road.

(2) Transported 10 miles over rough road

(3) Transported 2 miles across country.

(4) Trim pots adjusted.

(5) Sever cold (minus 50°F in warehouse) 2 days.

(6) Severe heat (140°F in warehouse) 12 hours.

(7) Serviced by maintenance section.

(8) Hit severe bump during transportation.

15-8. Taking Down the Instrument

a. After measurement is made with the azimuth gyro approximately 10 minutes is required from the time the gyro rotor is shut off until it comes to rest. To diminish this coasting time when the SELECTOR switch is in FWD, turn the SELECTOR switch to REV for 45 seconds and then to OFF; when the SELECTOR switch is in REV, turn the SELECTOR to FWD for 45 seconds and then to OFF. This method of power reversal brings the rotor nearly to a standstill. Monitor the rotation of the rotor by placing an ear against the sensing element.

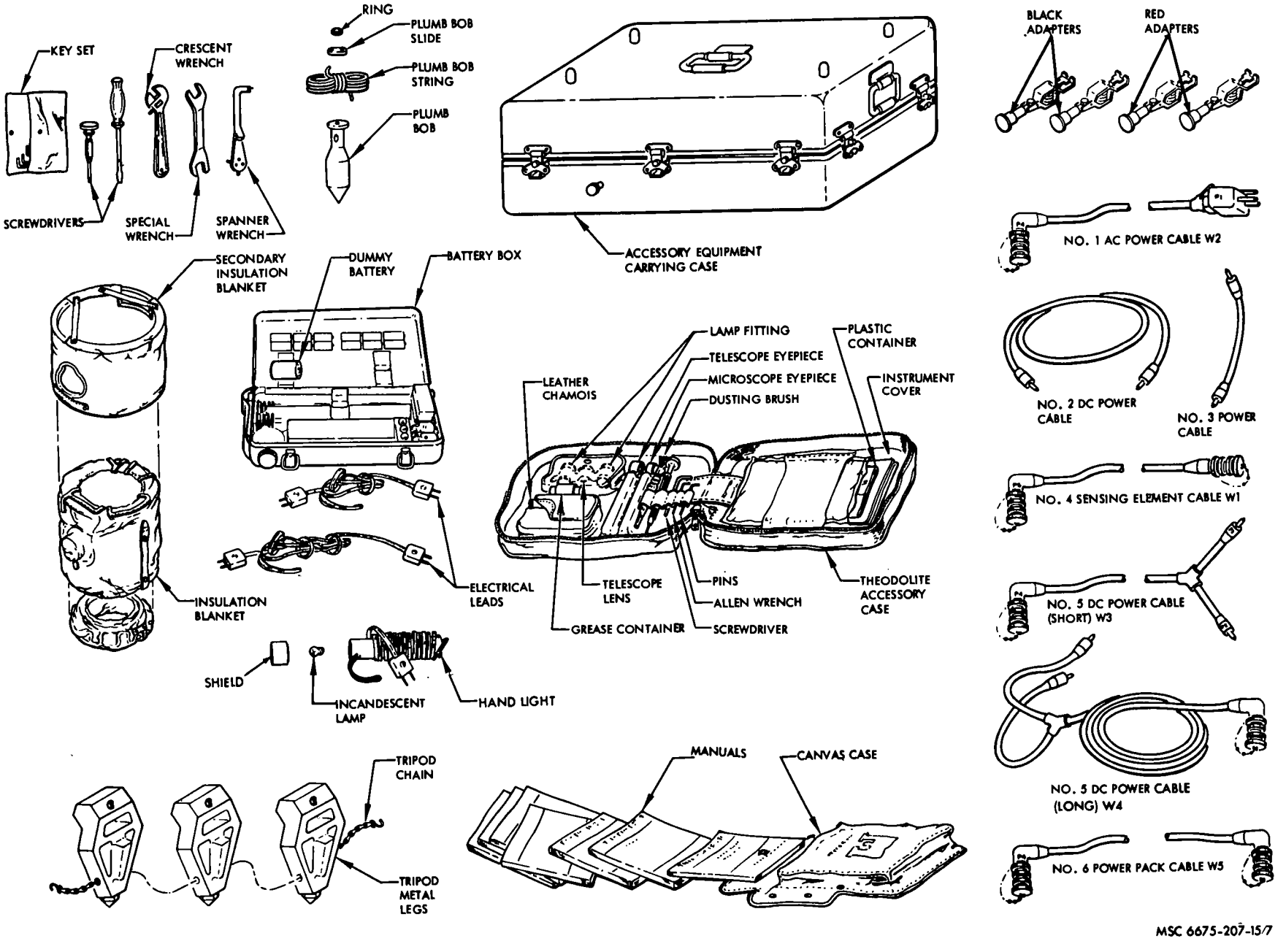


Figure 15–11. Accessory equipment carrying case and accessories Model C2A.

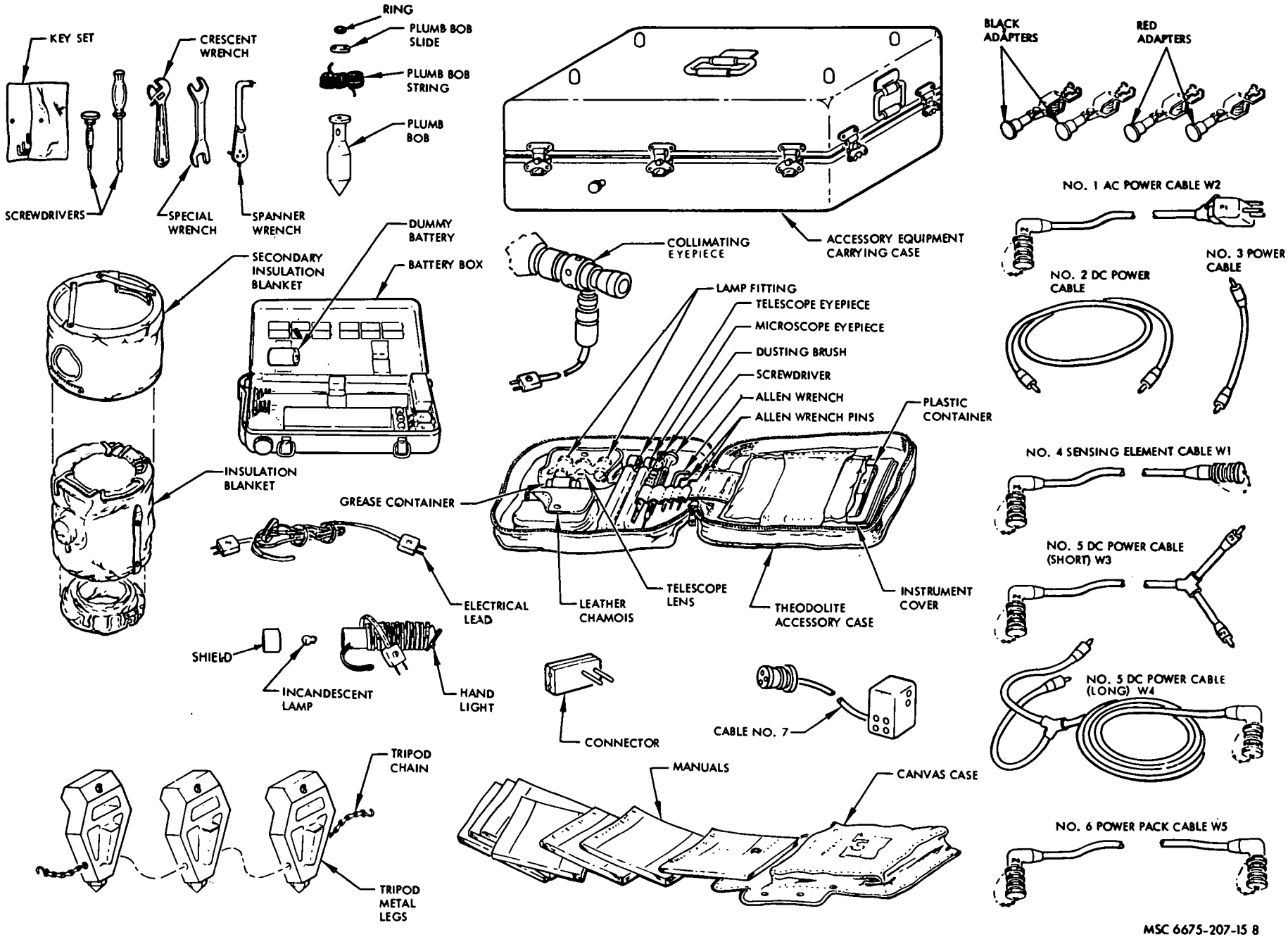


Figure 15–12. Accessory equipment carrying case and accessories Model C2B.

Caution: **To avoid possible damage or misalinement, never remove the sensing element from the tripod or transport the sensing element while the gyro rotor is running.**

b. Turn the SELECTOR AND CIRCUIT TEST switches to OFF and secure the azimuth lock with light pressure.

c. Disconnect the power source.

d. Disconnect cable number 4 from the sensing element.

e. Disconnect cables number 4, 6, and 1 (or 5) from the control indicator.

f. Store the cables in the canvas bag with the loose equipment.

g. Close the control indicator cover and secure the cover with the five latches.

h. If the sensing element is to be transported, remove the theodolite from the bracket and carry the theodolite in the issued theodolite base and carrying case.

i. Connect the carrying case heater wire to the sensing element connector.

i. Unscrew the tripod fixing screw and, using the two handles provided, remove the sensing lement from the tripod and carefully place in the carrying case.

k. Connect the heater wire from the sensing element to the bracket receptacle.

l. Position the collar and cushioning.

m. Check to see that tools are secure.

n. Install the carrying case cover and secure it with the six hook-type clamps.

o. Close the pressure relief valve and secure the dust cap on the electrical connector.

p. Clean, fold, and secure the tripod legs.

15–9. Care and Maintenance

Adjustment and repair of the azimuth gyro must be performed by qualified instrument repair personnel. Artillery units, therefore, should turn the instrument in for any necessary adjustments or repair to the engineer unit responsible for providing maintenance service. TM 5–6675–207–15 outlines the categories of maintenance for the instrument.

Section IV. DESTRUCTION OF EQUIPMENT

15–10. Destruction of Equipment

a. General. When capture or abandonment of the instrument to an enemy is imminent, the responsible unit commander must make the decision either to destroy the equipment or to render it inoperative. Based on this decision, orders are issued which cover the desired extent of destruction. Whatever method of demolition is employed, it is essential to destroy the same vital parts of all surveying instruments units and all corresponding repair parts.

b. Demolition of Equipment to Render Inoperative.

(1) *Mechanical means*—Using a hammer, bar or other suitable object, break all electronic components within the control-indicator. Destroy all controls. Break sensing element components (gyro, mirror assembly, and base), tripod bases, and 24 volt power supply.

(2) *Burning*—Pack oil-soaked rags, canvas, or other flammable material around the control indicator, sensing element, tripods, and 24 volt power supply and accessories and ignite. Be sure the burning is thorough and complete.

(3) *Submersion*—Remove the control-indicator and sensing element from respective carrying cases. Submerge the surveying instrument and all of the accessories in a body of water to insure water damage and provide concealment. Salt water will do the greatest damage to metal and electronic parts.

Note. Since the gyro is the most significant assembly of the surveying instrument, particular care should be taken to assure its complete destruction upon demolition of the equipment. Submersion by itself may not be adequate to destroy the gyro.

(4) *Weapons fire*—Fire repeatedly on the equipment with the heaviest practical weapon available.

(5) *Mobile means*—Run over the equipment with a heavy vehicle such as a truck or tank or drop the equipment from a height onto a hard surface.

CHAPTER 16
CONVERSION TO COMMON CONTROL

Section I. CONVERTING DATA

16–1. General

a. In order to permit the delivery of accurate field artillery fires without adjustment and to permit the massing of fires of two or more artillery units, all field artillery units operating under the tactical control of one commander should be located and oriented with respect to a single datum plane or grid, referred to as the *common grid.* This grid can be based on the UTM (UPS) grid coordinates of points previously established by survey, or the grid may be based on assumed data.

b. The common grid is established by the highest survey echelon present in the area. The headquarters which exercises tactical control over artillery units are battalion, division, and corps. The mission of the subordinate unit requires it to initiate survey operations without waiting for survey control to be established by a higher echelon. Thus, it may be necessary for a battalion assigned or attached to a division artillery to operate first on the grid established by the battalion (battalion grid), and finally on the grid established by corps artillery (corps grid). When survey at one or more echelons is based on assumed data, data established by the lower echelon must be converted to the grid established by the higher echelon. Unless the tactical situation causes the commander to decide otherwise, battalion (battery) data are converted to the data of the next higher echelon when data differs by:

(1) two mils are more in azimuth.

(2) ten meters or more in radial error.

(3) two meters or more in height.

16–2. Variations in Starting Control

The methods by which starting control for field artillery survey can be obtained are listed in order of preference in *a* through *c* below.

a. Use of Known Coordinates and Heights of Points Located With Respect to a UTM (or UPS) Grid. The points for which the coordinates and heights are known may be points established by surveys performed by the higher echelon, or they may be points which were located by surveys performed prior to the start of military operations. The locations of points established proir to the commencement of military operations are contained in trig lists prepared and published by the Corps of Engineers.

b. Use of Assumed Coordinates and Heights and Correct Grid Azimuth. Correct grid azimuth can be determined, in many cases, through astronomic observation or through the use of an azimuth gyro. Correct grid azimuth should always be used whenever possible. If both higher and lower survey echelons initiate surveys by using correct grid azimuths, any discrepancy which exists between surveys due to assumption of coordinates will be constant for all points located (fig 16–1). The approximate coordinates and height of the starting point can be determined from a large-scale map and should approximate the correct coordinates and height as closely as possible. The use of starting data determined from a map must always be considered as assumed data.

c. Use of Known or Assumed Coordinates and Assumed Azimuth. Assumed azimuth should be used for a starting azimuth only when azimuth cannot be determined by astronomic observations, an azimuth gyro, computations or obtained from a published trig list. The assumed azimuth should approximate the correct grid azimuth as closely as possible. The approximate grid azimuth can be determined by scaling from a large-scale map or by using a declinated aiming circle. If either (or both) higher or lower echelon survey operations are initiated with assumed azimuths, differences of varying magnitude will exist between the coordinates of points located by their surveys (fig 16–1). This variation complicates the problem of conversion to common control. For this reason, as-

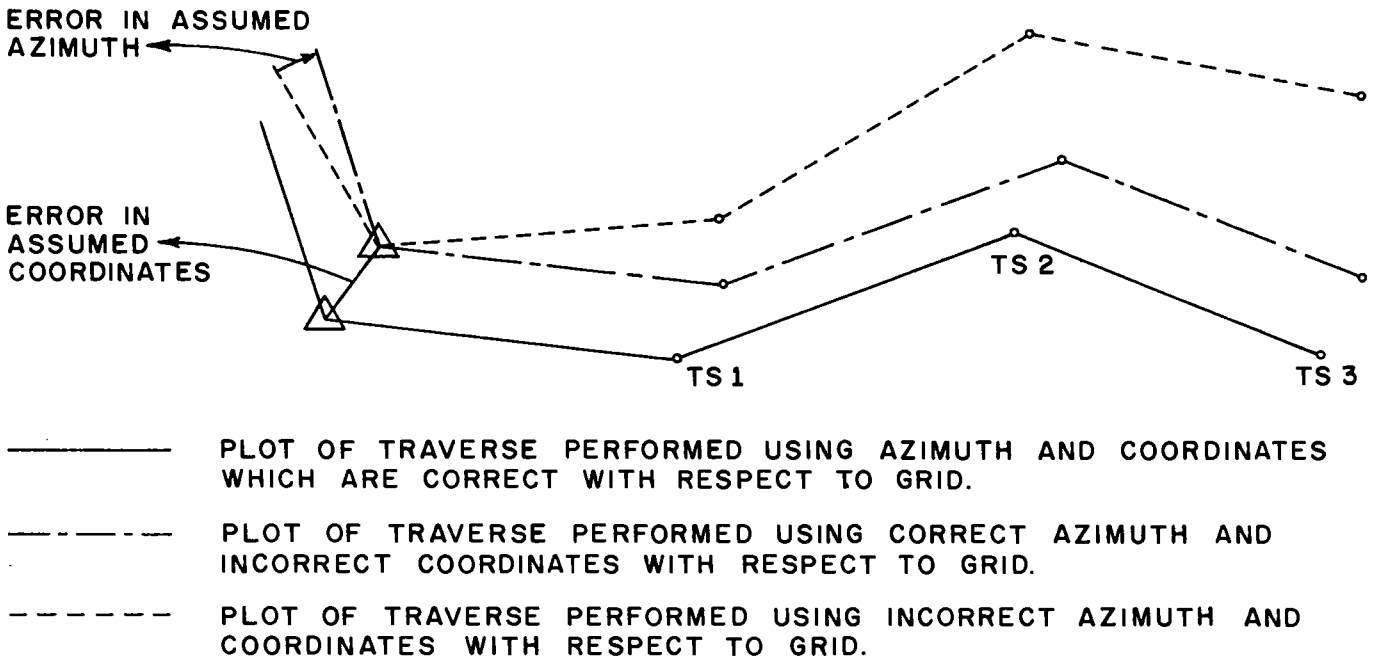


Figure 16-1. Discrepancies in survey control caused by use of assumed starting data.

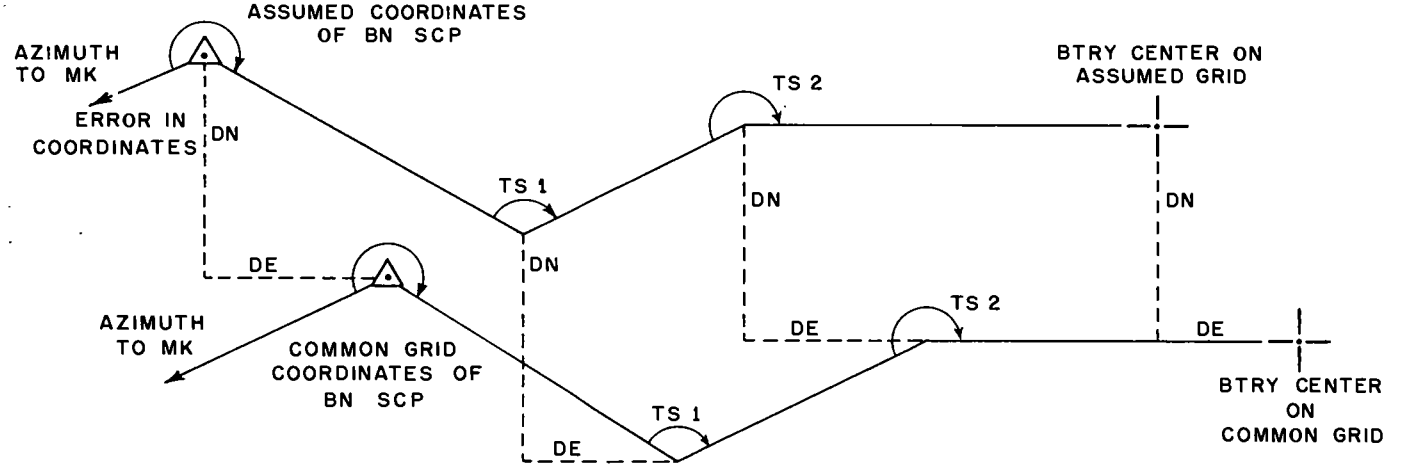


Figure 16-2. Schematic diagram illustrating sliding the grid.

sumed azimuth should never be used if the correct grid azimuth is known or can be determined.

16-3. Coodinates and Height Conversion (Sliding the Grid)

When both a higher and a lower survey echelon start survey operations with correct grid azimuth but one (or both) echelon(s) starts (start) with assumed coordinates and height, the lower echelon must apply coordinate and height corrections to the location of each critical point in their survey to convert to the grid of the higher echelon. This coordinate and height conversion is commonly referred to as *sliding the grid* (fig 16-2) and is accomplished as follows:

a. Determine the difference in easting and northing coordinates and the difference in height between the assumed coordinates and height of the starting point and the common grid coordinates and height of the starting point provided by the higher echelon.

	Easting	*Northing*	*Height*
Assumed Starting Point:	550000.00	3838000.00	400.0
Common Grid Starting Point:	550196.52	3837887.89	402.3
Correction	+ 196.52	— 112.11	+2.3

The difference becomes the correction when the difference is given a sign.

b. Add these corrections algebraically to the assumed data whcih will cause the resulting grid coordinates and height to equal the common grid coordinates and height.

16–4. Azimuth Conversion (Swinging the Grid)

If the unit initiates survey operations using common grid coordinates but an assumed azimuth for the starting point, the coordinates of each station in the survey and the azimuth determined by survey will be in error when correct direction is determined for the starting point. In order to convert the assumed data to correct grid data, all azimuths and coordinates determined in the scheme must be corrected. The application of the azimuth correction is commonly referred to as *swinging the grid.* The procedures for swinging the grid are as follows:

a. Determine the difference between the assumed starting azimuth and the azimuth obtained from common control.

Assumed Starting Azimuth.	2,800.0 mils
Common Grid Starting Azimuth:	2,922.7 mils
Azimuth Correction:	+ 122.7 mils

This difference is the azimuth correction that must be applied to the assumed data to cause the assumed azimuth to equal the common grid azimuth.

b. Apply the azimuth correction to each leg of the survey.

c. Since this will change the azimuth of each, the bearing angle of each leg will also change. Recompute each leg of the survey by using the corrected azimuths and new coordinates determined for each station in the survey, thus placing all stations on the common grid.

d. Very often, it is not necessary to correct the locations of all the stations in the survey. If only the coordinates of the final station (or specific sta-

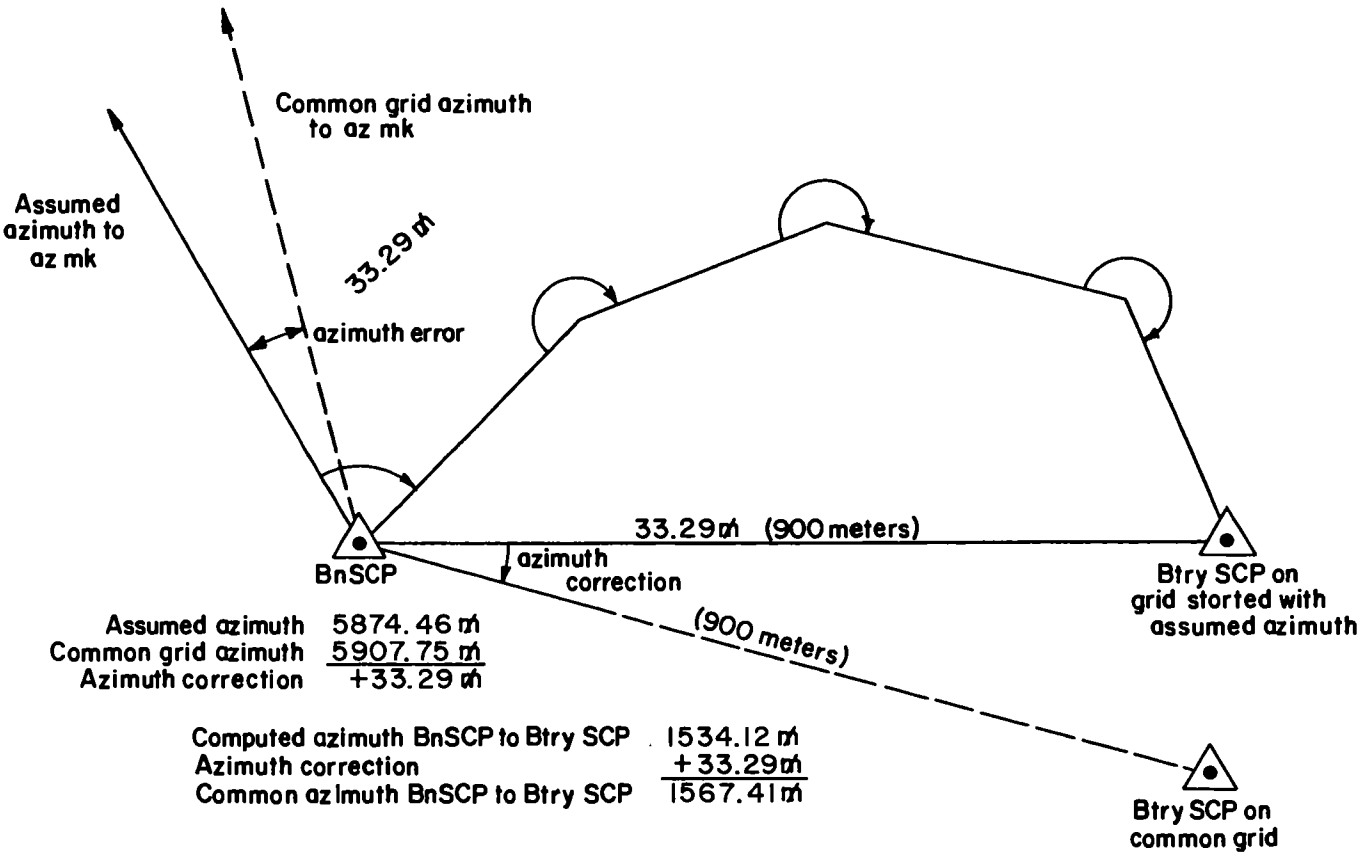


Figure 16–3. Swinging the grid for a specific station.

tions) in a traverse are needed, the grid is swung as follows (fig 16-3):

(1) Determine the difference between the assumed starting azimuth and the azimuth given by common control. This difference, with its appropriate sign, is an azimuth correction from the assumed azimuth to the common grid azimuth.

(2) Compute the azimuth and distance between the starting station and the required station, using the coordinates determined in the original survey.

(3) Apply the azimuth correction to the computed azimuth.

(4) Using the computed distance and the cor-

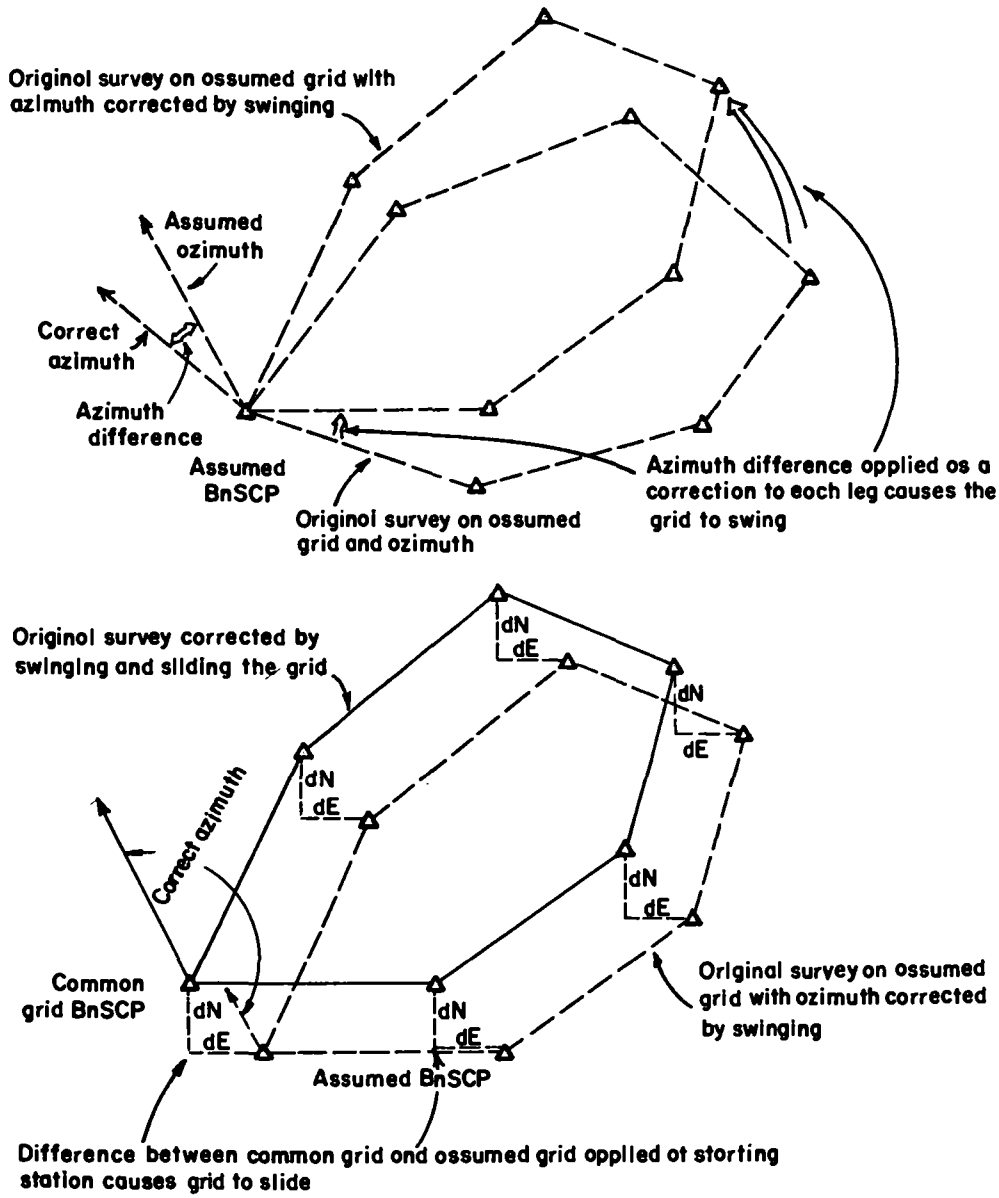


Fig. 16-4. Swinging and sliding the grid.

rected azimuth, recompute the coordinates of the required station.

e. To correct the azimuth of critical line (i.e., orienting line, target area base and azimuth of fire), apply the azimuth correction to the azimuth determined through the use of assumed data.

16–5. Azimuth, Coordinates, and Height Conversion (Swing and Sliding the Grid)

If either (or both) a higher or lower survey echelon initiates survey operation with assumed azimuth, coordinates, and height, the lower echelon must apply azimuth, coordinate, and height corrections to critical locations and directions to convert to the grid of the higher echelon. This technique is commonly referred to as *swinging and sliding the grid* and both swinging and sliding may be accomplished at the same time. Only the critical points (e.g., battery centers, Registrations Points, OP's) are converted. The steps in swinging and sliding the grid (fig 16–4) as follows:

a. Using the assumed coordinates, compute the azimuth and distance from the starting point to the first critical point and from the first critical point to the second critical point. Continue this sequence of computations until the closing point is reached.

b. Determine the azimuth correction by comparing the assumed starting azimuth with the common grid starting azimuth. Apply the azimuth correction to each of the computed azimuths determined in *a* above.

c. Using the *common* grid coordinates of the starting point, the corrected azimuths (*b* above), and the computed distances between critical points (*a* above), compute the coordinates of the first critical point. Using the new coordinates of the first critical point, the corrected azimuth, and the computed distance to the second point, recompute the coordinates of the second critical point and continue the computations until the closing point is reached, thus providing a check on the computation of the swinging and sliding correction.

d. Correct the height of the critical points by applying the height correction to the height of each critical point.

16–6. Swinging and Sliding the Grid (Graphically)

The procedures discussed in paragraph 16–5 require considerable mathematical computations in order to convert to common control. If time is critical, a graphical solution to conversion to common control can be used. However, control cannot be extended from data obtained from a graphical solution. Normally, the graphical solution is used in conjunction with a firing chart. An overlay is made of the existing critical points, including the battalion survey control point and a line of direction to the azimuth mark. Then the critical points are transferred to a new chart. The procedures are as follows:

a. Plot the coordinate locations, as determined from assumed data, for the battalion SCP, all critical points, and the azimuth (assumed) to the mark on the chart.

b. Place a sheet of overlay paper over the chart and prick the locations of all critical points to include the battalion SCP.

c. Trace the assumed azimuth from the battalion SCP on to the overlay.

d. Plot the common control coordinates at the battalion SCP and the common control azimuth to the azimuth mark on a new chart.

e. Place the overlay on the new chart, alining the assumed battalion SCP on the common grid battalion SCP and rotate the chart until the azimuth line on the overlay coincides with the azimuth line on the chart.

f. Prick the locations of all critical points shown on the overlay onto the new chart.

CHAPTER 17
CONVERSION AND TRANSFORMATION

Section I. CONVERSION

17-1. General

The universal transverse Mercator grid zones are 6° wide. There are 60 such zones surrounding the earth. At the Equator, each of these zones is approximately 360 nautical miles in width. In moving north or south from the Equator, each zone decreases in width. In the universal transverse Mercator grid system, there are overlap areas east and west of zone junctions. From time to time, it is possible that some survey operations may take place at the junctions of these zones, and it is highly probable that with the advent of missiles and longer range field artillery, requirements will exist to fire from one zone to another. Since field artillery operations will span such large areas, survey personnel may find it necessary to convert coordinates from geographic to grid in those areas where existing survey is available only in geographic coordinates.

17-2. Tables and References for Conversion

Tables and references required for conversion computations are dependent on the spheroid that is used for the particular locality. Throughout the earth, there are several spheroids which are used for the shape of the earth for the purpose of computing geodetic positions. The spheroid for a particular locality may be determined by referring to TM 5-241-1, plate 1. The tables required for the various spheroids are as follows:

a. International Spheroid—(South American, Europe, Australia (New spheroid pending), Greenland, China and other parts of Asia, North Africa, Hawaii, South Pacific and U.S.S.R.): TM 5-241-3/1 and TM 5-241-3/2.

b. Clarks 1866 Spheroid—(United States, Mexico, Alaska, Canada, and Philippine Islands): TM 5-241-4/1 and TM 5-241-4/2.

c. Bessel Spheroid—(Japan, Korea, Borneo, Celebes, and Sumatra): TM 5-241-5/1 and TM 5-241-5/2.

d.. Clarke 1880 Spheroid—(South Africa) TM 5-241-6/1 and TM 5-241-6/2.

e. Everest Spheroid—(India, Tibet, Burma, Malay, Thailand, Cambodia, and Vietnam): TM 5-241-7.

17-3. Formulas for Conversion

The formulas used in conversion computation are as follows:

$E' = (IV)_p + (V)_p 3 + B_s$

$N = (I) + (II)_p 2 + (III)_p 4 + A_s$

Where, E′ = The difference between the easting of the station and that of the central meridian of the grid zone. To obtain the easting of the station, E′ is added to 500,000 if the station is east of the central meridian; subtracted, if it is west.

N = Northing of the station. In the Southern Hemisphere N must be subtracted from 10,000,000.

P = The difference between the longitude of the central meridian of the grid zone and that of the station in seconds of arc, with the decimal point moved left four places.

I = Function in terms of the latitude to the nearest thousandth of a second. This value is extracted from Volume I for the proper spheroid.

II = Function in terms of the latitude to the nearest thousandth of a second taken from the same volume.

III = Function in terms of the latitude to the nearest minute taken from the same volume.

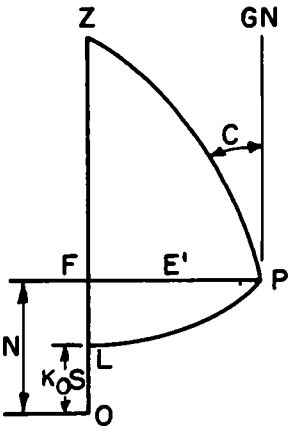
IV = Function in terms of the latitude to the nearest thousandth of a second taken from the same volume. To this value must be applied a small correction, (IV), which is extracted from a ladder graph in the same volume using the seconds of latitude as the entering argument. The correction increases from 0 to 30 seconds then decreases to 0 again within each minute of latitude.

V = Function in terms of the latitude to the nearest thousandth of a second taken from the same volume.

B_s = Function in terms of the approximate latitude and the longitude difference taken from a nomogram type of graph in the same volume.

A_s = Function in terms of the difference in longitude taken from the same volume.

Figure 17-1 illustrates those elements of the universal transverse Mercator projection which enter



Note: Both formulas (N and E') are based on the product of longitude difference and latitude and the corresponding corrections for spheroid curvature.

Figure 17–1. Schematic drawing illustrating elements of the universal transverse mercator projection used in conversion computations.

into conversion computations. With the point P as the point under consideration and OZ representing the central meridian, the distance E′ represents the distance from the central meridian to point P (difference in easting). The line OF represents the grid northing (N). The line PZ represents the meridian of the point under consideration, and angle C equals the convergence. k_0s represents the meridianal arc from the Equator to the parallel of latitude of point P and is corrected by use of the log scale factor previously discussed. In addition, since the perpendicular from P to the central meridian does not follow the earth's surface, the distance LF represents the ordinate of curvature and is computed in the furmulas as the factor I.

Note. Both formulas (N and E′) are based on the product of longitude difference and latitude and the corresponding corrections for spheroid curvature.

17–4. Powers of p Relative to Accuracy

In the formulas for conversion, the second part of many of the terms involves the longitude through the quantity $_p$, which is one ten-thousandth of the difference of the longitude from the central meridian to the desired point expressed in seconds. To produce $_p$, the difference in longitude is converted to seconds and the decimal moved four places to the left. The powers of $_p$ are produced either by machine multiplication or by logarithms. The following table gives the number of decimal places, D, to which $_p$ should be carried to give a specified accuracy in the coordinates.

	1 meter	*0.1 meter*	*0.01 meter*
P	6 D	7 D	8 D
P^2	4	5	7
P^3	3	4	6
P^4	1	2	4

17–5. Graphical Terms Used in Conversion Formulas

Note. For a complete understanding of the discussions follow refer to the appropriate technical manual for the designated spheroid and to the section of that volume titled "Tables for Transformation of Coordinates from Geographic to Grid" (pages extracted as fig 17–2 and 17–3).

a. Term A_6. The term A_6 (fig 17–3) denotes the product of a latitude function by P_6, similar to (III) p4. This product is represented by a ladder graph at the bottom of the right-hand page on each table for each degree of latitude. The left-hand side of this graph and of the B_5 graph (*b* below) carries the value of the longitudinal difference (desired point to control meridian) in degrees and minutes; the right hand side is the correction in meters. It is necessary to pay attention to the sign marked on the right-hand side and to apply the correction accordingly.

b. Term B_5. The term B_5 (fig 17–3) is similar to A6, but it changes with latitude so rapidly that the ladder graph cannot be used; consequently a nomogram is necesssary. The term is found by first entering at the top of the nomogram with the appropriate latitude, then reading down to the proper longitudinal difference, and then project-

UNIVERSAL TRANSVERSE MERCATOR GRID

$p = .0001\Delta\lambda''$

N of Equator $N = (I)p^2 + (II)p^2 + (III)p^4 = A_6$

S of Equator $N = 10,000,000 - [(I) + (II)p^2 + (III)p^4 + A_6]$

Latitude	(I)	Diff. 1"	(II)	Diff. 1"	(III)
34°00'	3 761 961.527	30.79859	3 477.287	0.01367	2.147
01	3 763 809.443	30.79869	3 478.107	0.01365	2.147
02	3 765 657.364	30.79876	3 478.925	0.01363	2.146
03	3 767 505.290	30.79884	3 479.743	0.01361	2.145
04	3 769 353.220	30.79894	3 480.559	0.01359	2.145
34 05	3 771 201.157	30.79903	3 481.375	0.01357	2.144
06	3 773 049.098	30.79911	3 482.189	0.01355	2.144
07	3 774 897.045	30.79919	3 483.002	0.01353	2.143
08	3 776 744.996	30.79928	3 483.813	0.01351	2.142
09	3 778 592.953	30.79936	3 484.624	0.01349	2.142
34 10	3 780 440.915	30.79944	3 485.433	0.01347	2.141
11	3 782 288.881	30.79954	3 486.241	0.01345	2.141
12	3 784 136.854	30.79961	3 487.048	0.01343	2.140
13	3 785 984.830	30.79969	3 487.854	0.01341	2.139
14	3 787 832.812	30.79979	3 488.659	0.01339	2.139
34 15	3 789 680.799	30.79988	3 489.462	0.01337	2.138
16	3 791 528.792	30.79994	3 490.265	0.01335	2.137
17	3 793 376.788	30.80004	3 491.066	0.01333	2.137
18	3 795 224.791	30.80013	3 491.866	0.01331	2.136
19	3 797 072.798	30.80021	3 492.664	0.01329	2.136
34 20	3 798 920.811	30.80029	3 493.462	0.01327	2.135
21	3 800 768.828	30.80037	3 494.258	0.01325	2.134
22	3 802 616.851	30.80046	3 495.054	0.01323	2.134
23	3 804 464.878	30.80054	3 495.848	0.01321	2.133
24	3 806 312.911	30.80064	3 496.640	0.01319	2.132
34 25	3 808 160.949	30.80072	3 497.432	0.01317	2.132
26	3 810 008.993	30.80079	3 498.223	0.01315	2.131
27	3 811 857.040	30.80089	3 499.012	0.01314	2.130
28	3 813 705.094	30.80097	3 499.800	0.01312	2.130
29	3 815 553.152	30.80106	3 500.587	0.01310	2.129
34 30	3 817 401.215	30.80114	3 501.373	0.01308	2.128
31	3 819 249.284	30.80124	3 502.157	0.01306	2.128
32	3 821 097.358	30.80131	3 502.941	0.01304	2.127
33	3 822 945.437	30.80139	3 503.723	0.01302	2.126
34	3 824 793.520	30.80149	3 504.504	0.01300	2.126
34 35	3 826 641.610	30.80157	3 505.284	0.01298	2.125
36	3 828 489.704	30.80164	3 506.062	0.01296	2.124
37	3 830 337.803	30.80174	3 506.840	0.01294	2.124
38	3 832 185.907	30.80182	3 507.616	0.01292	2.123
39	3 834 034.017	30.80191	3 508.391	0.01290	2.122
34 40	3 835 882.131	30.80199	3 509.165	0.01288	2.122
41	3 837 730.251	30.80209	3 509.938	0.01286	2.121
42	3 839 578.376	30.80217	3 510.709	0.01284	2.120
43	3 841 426.507	30.80224	3 511.480	0.01282	2.120
44	3 843 274.641	30.80234	3 512.249	0.01280	2.119
34 45	3 845 122.781	30.80242	3 513.017	0.01278	2.118
46	3 846 970.927	30.80251	3 513.784	0.01276	2.118
47	3 848 819.077	30.80259	3 514.549	0.01274	2.117
48	3 850 667.233	30.80267	3 515.314	0.01272	2.116
49	3 852 515.393	30.80277	3 516.077	0.01270	2.116
34 50	3 854 363.560	30.80286	3 516.839	0.01268	2.115
51	3 856 211.731	30.80292	3 517.600	0.01266	2.114
52	3 858 059.907	30.80302	3 518.360	0.01264	2.114
53	3 859 908.088	30.80311	3 519.118	0.01262	2.113
54	3 861 756.274	30.80319	3 519.875	0.01260	2.112
34 55	3 863 604.466	30.80327	3 520.631	0.01258	2.112
56	3 865 452.662	30.80337	3 521.386	0.01256	2.111
57	3 867 300.865	30.80344	3 522.140	0.01254	2.110
58	3 869 149.071	30.80352	3 522.893	0.01252	2.109
59	3 870 997.282	30.80362	3 523.644	0.01250	2.109
35 00	3 872 845.500		3 524.394		2.108

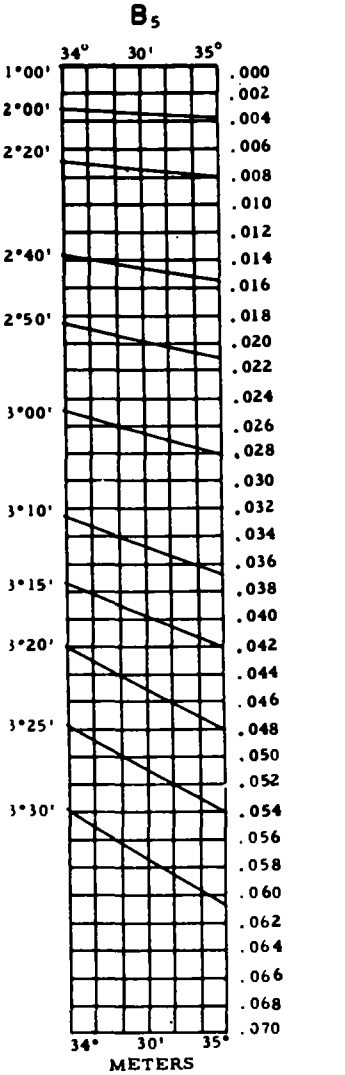
Figure 17-2. Extract page 70, TM 5-241-4/1.

CLARK 1866 SPHEROID METERS

$E' = (IV)p + (V)p^3 + B_5$

$p = .0001\Delta\lambda''$

Latitude	(IV)	Diff. 1"	(V)	Diff. 1"
34°00'	256 527.533	-0.83514	37.969	-0.00103
01	256 477.424	0.83551	37.907	0.00103
02	256 427.293	0.83587	37.845	0.00103
03	256 377.142	0.83623	37.783	0.00103
04	256 326.968	0.83659	37.721	0.00103
34 05	256 276.772	-0.83695	37.659	-0.00103
06	256 226.555	0.83732	37.597	0.00103
07	256 176.316	0.83768	37.536	0.00103
08	256 126.055	0.83804	37.474	0.00103
09	256 075.773	0.83840	37.412	0.00103
34 10	256 025.469	-0.83876	37.350	-0.00103
11	255 975.143	0.83913	37.288	0.00103
12	255 924.796	0.83949	37.226	0.00103
13	255 874.426	0.83985	37.165	0.00103
14	255 824.035	0.84021	37.103	0.00103
34 15	255 773.623	-0.84057	37.041	-0.00103
16	255 723.189	0.84093	36.979	0.00103
17	255 672.733	0.84129	36.917	0.00103
18	255 622.255	0.84165	36.856	0.00103
19	255 571.756	0.84202	36.794	0.00103
34 20	255 521.235	-0.84238	36.732	-0.00103
21	255 470.692	0.84274	36.670	0.00103
22	255 420.128	0.84310	36.609	0.00103
23	255 369.542	0.84346	36.547	0.00103
24	255 318.935	0.84382	36.485	0.00103
34 25	255 268.305	-0.84418	36.423	-0.00103
26	255 217.655	0.84454	36.362	0.00103
27	255 166.982	0.84490	36.300	0.00103
28	255 116.288	0.84526	36.238	0.00103
29	255 065.572	0.84562	36.177	0.00103
34 30	255 014.835	-0.84598	36.115	-0.00103
31	254 964.076	0.84634	36.053	0.00103
32	254 913.295	0.84670	35.991	0.00103
33	254 862.493	0.84706	35.930	0.00103
34	254 811.669	0.84742	35.868	0.00103
34 35	254 760.824	-0.84778	35.806	-0.00103
36	254 709.957	0.84814	35.745	0.00103
37	254 659.068	0.84850	35.683	0.00103
38	254 608.158	0.84886	35.622	0.00103
39	254 557.226	0.84922	35.560	0.00103
34 40	254 506.273	-0.84958	35.498	-0.00103
41	254 455.298	0.84994	35.437	0.00103
42	254 404.301	0.85030	35.375	0.00103
43	254 353.283	0.85066	35.313	0.00103
44	254 302.244	0.85102	35.252	0.00103
34 45	254 251.182	-0.85138	35.190	-0.00103
46	254 200.100	0.85174	35.129	0.00103
47	254 148.995	0.85210	35.067	0.00103
48	254 097.869	0.85246	35.005	0.00103
49	254 046.722	0.85282	34.944	0.00103
34 50	253 995.553	-0.85318	34.882	-0.00103
51	253 944.363	0.85353	34.821	0.00103
52	253 893.151	0.85389	34.759	0.00103
53	253 841.917	0.85425	34.698	0.00103
54	253 790.662	0.85461	34.636	0.00103
34 55	253 739.385	-0.85497	34.575	-0.00103
56	253 688.087	0.85533	34.513	0.00103
57	253 636.768	0.85569	34.452	0.00103
58	253 585.427	0.85604	34.390	0.00102
59	253 534.064	0.85640	34.329	0.00102
35 00	253 482.680		34.267	



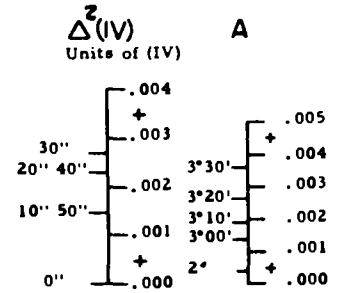


Figure 17-3. Extract page 71, TM 5-241-4/1.

COMPUTATION - CONVERSION GEOGRAPHIC COORDINATES TO UTM GRID COORDINATES *(MACHINE)*

For use of this form, see FM 6-2; the proponent agency is United States Continental Army Command.

STATION	LATITUDE	LONGITUDE	HEMISPHERE
SILL	34 ° 38 ' 31.738 "	98 ° 23 ' 14.830 " ☐ EAST ☒ WEST	☒ NORTH ☐ SOUTH

1	LONGITUDE OF STATION *(As accurately as known)*	98 ° 23 ' 14.830 "	22*	TABULAR VALUE FUNCTION IV OPPOSITE LATITUDE *(Degrees, minutes)* OF STATION	254 608 158
2	LONGITUDE OF CENTRAL MERIDIAN OF UTM GRID ZONE BEING USED	99 °	23*	TABULAR DIFFERENCE FOR 1 SECOND OPPOSITE FUNCTION IV IN *(22)* (−)	0 848 186
3	IF *(1)* IS MORE THAN *(2)*, USE *(1)*−*(2)* IF *(1)* IS LESS THAN *(2)*, USE *(2)*−*(1)* *(Sign always +)* (+)	98 ° 23 ' 14.830 " 0 ° 36 ' 45.170 "	24*	TABULAR VALUE FUNCTION V OPPOSITE LATITUDE *(Degrees, minutes)* OF STATION (+)	35 622
4	CONVERT *(3)* TO SECONDS OF ARC	22 05 . 170 "	25*	TABULAR DIFFERENCE FOR 1 SECOND OPPOSITE FUNCTION V IN *(24)* (+)	0 001 03
5	REPEAT *(4)* WITH DECIMAL POINT MOVED LEFT FOUR PLACES	0 220 517 0	26*	GRAPHIC VALUE B_S [USE LATITUDE *(Degrees, minutes)* AS ARGUMENT AT TOP OF GRAPH. USE VALUE IN STEP *(3)* AS ARGUMENT AT LEFT SIDE OF GRAPH] (+)	0 000
6	*(5)* X *(5)*	0 048 627 8	27*	GRAPHIC VALUE Δ^2 *(IV)* [USE LATITUDE *(Seconds)* OF STATION AS ARGUMENT. ENTER GRAPH AT LEFT SIDE] (+)	003
7	*(6)* X *(5)*	0 010 723			
8	*(7)* X *(5)*	0 002 4	28	*(23)* X LATITUDE *(Seconds)* OF STATION (−)	26 941
9*	TABULAR VALUE FUNCTION I OPPOSITE LATITUDE *(Degrees, minutes)* OF STATION	3 832 185 907	29	*(25)* X LATITUDE *(Seconds)* OF STATION (+)	0 033
10*	TABULAR DIFFERENCE FOR 1 SECOND OPPOSITE FUNCTION I IN *(9)*	30 801 82	30	ALGEBRAIC SUM *(26)* AND *(29)* (+)	35 589
11*	TABULAR VALUE FUNCTION II OPPOSITE LATITUDE *(Degrees, minutes)* OF STATION	3 507 616	31	*(30)* X *(7)* (+)	0 382
12*	TABULAR DIFFERENCE FOR 1 SECOND OPPOSITE FUNCTION II IN *(11)* (+)	0 012 92	32	ALGEBRAIC SUM *(22)*, *(27)*, AND *(28)* *(Sign always +)* (+)	254 581 220
13*	TABULAR VALUE FUNCTION III OPPOSITE LATITUDE *(Degrees, minutes)* OF STATION (+)	2 123	33	*(32)* X *(4)* *(Sign always +)* (+)	56 139 487
14*	GRAPHIC VALUE A_6 [USE VALUE IN STEP *(3)* AS ARGUMENT. ENTER GRAPH AT LEFT SIDE] (+)	0 000	34	ALGEBRAIC SUM *(32)*, *(31)*, AND *(33)* *(Sign always +)* (+)	56 139 869
15	*(10)* X LATITUDE *(Seconds)* OF STATION (+)	977 588	35	EASTING UTM GRID COORDINATE OF STATION IF LONGITUDE IS EAST AND *(1)* IS MORE THAN *(2)*, USE 500,000.000 + *(34)* IF LONGITUDE IS EAST AND *(1)* IS LESS THAN *(2)*, USE 500,000.000 − *(34)* IF LONGITUDE IS WEST AND *(1)* IS MORE THAN *(2)*, USE 500,000.000 − *(34)* IF LONGITUDE IS WEST AND *(1)* IS LESS THAN *(2)*, USE 500,000.000 + *(34)*	500 000 000 556 139 87
16	*(12)* X LATITUDE *(Seconds)* OF STATION (+)	0 410			
17	ALGEBRAIC SUM *(11)* AND *(16)* *(Sign always +)* (+)	3 508 026			
18	*(17)* X *(6)* (+)	170 588			
19	*(13)* X *(4)* (+)	0 005			
20	ALGEBRAIC SUM *(9)*, *(14)*, *(15)*, *(18)*, AND *(19)* *(Sign always +)*	3 833 334 088			
21	NORTHING UTM GRID COORDINATE OF STATION IF HEMISPHERE OF STATION IS NORTH, REPEAT *(20)* IF HEMISPHERE OF STATION IS SOUTH, USE 10,000,000.000 − *(20)*	3 833 334 09			

*OBTAINED FROM UTM GRID TABLES FOR SPHEROID BEING USED, VOLUME I

COMPUTER: SGT J. White

CHECKER: PFC R. Dixon

DATE: 5 Oct 68

DA FORM 1 SEP 52 6-25

Figure 17–4. DA Form 6–25, computation—conversion geographic coordinates to UTM grid coordinates (machine).

COMPUTATION CONVERSION GEOGRAPHIC COORDINATES TO UTM GRID COORDINATES *(Logarithms)*

(FM 6-2)

STATION: SILL — HEMISPHERE: [X] NORTH [ ] SOUTH

LATITUDE: 34° 38′ 31.738″ — LONGITUDE: 98° 23′ 14.830″ — [ ] EAST [X] WEST

1	LONGITUDE OF STATION *(as accurately as known)*	98° 23′ 14.830″			
2	LONGITUDE OF CENTRAL MERIDIAN OF UTM GRID ZONE BEING USED	99°			

3	IF (1) IS MORE THAN (2), USE (1)-(2)
	IF (1) IS LESS THAN (2), USE (2)-(1)
	(Sign always +) (+)
		98° 23′ 14.830″			

4	CONVERT (3) TO SECONDS OF ARC	0° 36′ 45.170″			
5	REPEAT (4) WITH DECIMAL POINT MOVED LEFT FOUR PLACES	2 205.170			
6	LOG (5)	0.220 517 0			
7	REPEAT (6)	9.343 4421			
8	(6) + (7)	9.343 4421			
9	REPEAT (6)	8.686 8842			
10	(8) + (9)	9.343 4421			
11	REPEAT (6)	8.030 3263			
12	(10) + (11)	9.343 4421			
13	TABULAR VALUE FUNCTION I OPPOSITE LATITUDE *(Degrees, Minutes)* OF STATION (+)	7.373 7684			
14	TABULAR DIFFERENCE FOR 1 SECOND OPPOSITE FUNCTION I IN (13) (+)	3 832 185.907			
15	TABULAR VALUE FUNCTION II OPPOSITE LATITUDE *(Degrees, Minutes)* OF STATION (+)	30 801 82			
16	TABULAR DIFFERENCE FOR 1 SECOND OPPOSITE FUNCTION II IN (15) (+)	3 507.616			
17	TABULAR VALUE FUNCTION III OPPOSITE LATITUDE *(Degrees, Minutes)* OF STATION (+)	0.012 92			
18	GRAPHIC VALUE A_S *(Use value in Step (3) as argument. Enter Graph at left side)* (+)	2.123			
19	LOG *(seconds)* LATITUDE OF STATION *(Use seconds part of latitude of station shown at top of computation)*	0.000			
20	LOG (14)	1.501 5796			
21	(19) + (20)	1.488 5764			
22	REPEAT (19)	2.990 1560			
23	LOG (16)	1.501 5796			
24	(22) + (23)	8.111 2625			
25	REPEAT (15) (+)	9.612 8421			
26	NUMBER HAVING LOG (25) IF SIGN OF (25) IS (+), USE SIGN (+) IF SIGN OF (25) IS (-), USE SIGN (-) (+)	3.507.616			
27	ALGEBRAIC SUM (25) AND (26) *(Sign always +)* (+)	0.410			
28	LOG (27)	3.508.026			
29	REPEAT (8)	3.545 0628			
30	(28) + (29)	8.686 8842			
31	LOG (17)	2.231 9470			
32	REPEAT (12)	0.326 9500			
33	(31) + (32)	7.373 7684			
34	NUMBER HAVING LOG (33) IF SIGN OF (33) IS (+), USE SIGN (+) IF SIGN OF (33) IS (-), USE SIGN (-) (+)	7.700 7184			
35	REPEAT (18) (+)	0.005			
36	ALGEBRAIC SUM (34) AND (35) (+)	0.000			
37	REPEAT (13) (+)	0.005			
38	NUMBER HAVING LOG (21) *(Sign always +)* (+)	3 832 185.907			
39	NUMBER HAVING LOG (30) *(Sign always +)* (+)	977.588			
40	(37) + (38) + (39) (+)	170.587			
41	REPEAT (36) (+)	3 833 334.082			
42	ALGEBRAIC SUM (40) AND (41) *(Sign always +)* (+)	0.005			
43	NORTHING UTM GRID COORDINATE OF STATION IF HEMISPHERE OF STATION IS NORTH REPEAT (42) IF HEMISPHERE OF STATION IS SOUTH, USE 10,000,000.000 - (42)-	3 833 334.087			
44	TABULAR VALUE FUNCTION IV OPPOSITE LATITUDE *(Degrees, Minutes)* OF STATION (+)				254.608.158
45	TABULAR DIFFERENCE FOR 1 SECOND OPPOSITE FUNCTION IV IN (44) (-)				0.848 86
46	TABULAR VALUE FUNCTION V OPPOSITE LATITUDE *(Degrees, Minutes)* OF STATION (+)				35.622
47	TABULAR DIFFERENCE FOR 1 SECOND OPPOSITE FUNCTION V IN (46) (+)				0.001 03
48	GRAPHIC VALUE B_S [USE LATITUDE *(Degrees, Minutes)* AS ARGUMENT AT TOP OF GRAPH. USE VALUE IN STEP (5) AS ARGUMENT AT LEFT SIDE OF GRAPH] (+)				0.000
49	GRAPHIC VALUE Δ^2 (IV) [USE LATITUDE *(Seconds)* OF STATION AS ARGUMENT. ENTER GRAPH AT LEFT SIDE] (+)				003
50	REPEAT (44) (+)				254.608.158
51	(49) + (50) (+)				254.608.161
52	LOG (45)				9.928 8361
53	REPEAT (19)				1.501 5796
54	(52) + (53)				1.430 4157
55	LOG (47)				7.012 8372
56	REPEAT (19)				1.501 5796
57	(55) + (56)				8.514 4168
58	REPEAT (46) (+)				35.622
59	NUMBER HAVING LOG (57) [USE SIGN OF (47)] (+)				0.033
60	ALGEBRAIC SUM (58) AND (59) (+)				35.589
61	LOG (60)				1.551 3158
62	REPEAT (10)				8.030 3263
63	(61) + (62)				9.581 6421
64	REPEAT (51) (+)				254.608.161
65	NUMBER HAVING LOG (58) (-)				26.941
66	ALGEBRAIC SUM (64) AND (65) *(Sign always +)* (+)				254.581.220
67	LOG (66)				5.405 8264
68	REPEAT (6)				9.343 4421
69	(67) + (68)				4.749 2685
70	NUMBER HAVING LOG (63) [USE SIGN OF (63)] (+)				0.382
71	REPEAT (48) (+)				0.000
72	ALGEBRAIC SUM (70) AND (71) (+)				0.382
73	NUMBER HAVING LOG (69) *(Sign always +)* (+)				56.139.494
74	REPEAT (72) (+)				0.382
75	ALGEBRAIC SUM (73) AND (74) *(Sign always +)* (+)				56.139.876
76	EASTING UTM GRID COORDINATE OF STATION IF LONGITUDE IS EAST AND (1) IS MORE THAN (2), USE 500,000.000 + (75) IF LONGITUDE IS EAST AND (1) IS LESS THAN (2), USE 500,000.000 - (75) IF LONGITUDE IS WEST AND (1) IS MORE THAN (2), USE 500,000.000 - (75) IF LONGITUDE IS WEST AND (1) IS LESS THAN (2), USE 500,000.000 + (75)				500 000 000
					556 139 88

*Obtained from UTM Grid Tables for spheroid being used, Volume I

COMPUTER: SGT J. White

CHECKER: PFC R. Dixon

DATE: 5 Oct 68

DA FORM 1 OCT 63 6-23 — REPLACES DA FORM 6-23, 1 SEP 52, EXISTING SUPPLIES OF WHICH WILL BE ISSUED AND USED UNTIL 1 OCT 64 UNLESS SOONER EXHAUSTED.

Figure 17-5. DA Form 6-23, computation—conversion geographic coordinates to UTM grid coordinates (logarithms).

COMPUTATION - CONVERSION UTM GRID COORDINATES TO GEOGRAPHIC COORDINATES (Machine)

For use of this form, see FM 6-2; the proponent agency is the United States Continental Army Command.

STATION: O'CONNER

UTM GRID COORDINATES: E 554 782 65 N 3 834 196 47

HEMISPHERE: [X] NORTH [ ] SOUTH

UTM GRID ZONE NUMBER: 14

1	EASTING COORDINATE OF STATION (As accurately as known)	554 782 65	25°	TABULAR VALUE FUNCTION IX OPPOSITE LATITUDE IN (10)	39 283 898
2		6 0 0 000 000	26°	TABULAR DIFFERENCE FOR 1 SECOND OPPOSITE TABULAR VALUE OF FUNCTION IX IN (35)	0 131 08
3	IF (1) IS MORE THAN (3), USE (1) - (2) IF (1) IS LESS THAN (3), USE (2) - (1) (Sign always +) (+)	54 782 65	27°	TABULAR VALUE FUNCTION X OPPOSITE LATITUDE IN (10)	315 001
			28°	TABULAR DIFFERENCE FOR 1 SECOND OPPOSITE TABULAR VALUE OF FUNCTION X IN (37)	004 22
4	REPEAT (3) WITH DECIMAL POINT MOVED LEFT SIX PLACES	054 782 65	29°	GRAPHIC VALUE $\Delta^2(IX)$ [USE (17) AS ARGUMENT. ENTER GRAPH AT LEFT SIDE (Sign always -)] (-)	000
5	(4) X (4)	003 001 139	30°	GRAPHIC VALUE E_5 = SECONDS OF ARC [USE STEP (4) AS ARGUMENT AT LEFT SIDE OF GRAPH. USE STEP (20) AS ARGUMENT AT TOP OF GRAPH]	000
6	(5) X (4)	000 164 410			
7	(6) X (4)	000 009 007	31	(17) X (26)	0 691
8	NORTHING COORDINATE OF STATION [(As accurately as known) IF HEMISPHERE IS SOUTH, USE 10,000,000.000 MINUS NORTHING COORDINATE OF STATION]	10 000 000 000	32	ALGEBRAIC SUM (23), (29), AND (31) (Sign always +) (+)	39 284 589
			33	(32) X (4) = SECONDS OF ARC (Sign always +) (+)	2 152 114
		3 834 196 470	34	(17) X (28)	0 022
9°	TABULAR VALUE FUNCTION I NEAREST TO AND LESS THAN VALUE IN (8)	3 834 034 017	35	(34) + (27)	315 023
10°	LATITUDE IN DEGREES AND MINUTES OPPOSITE VALUE IN (9)	° ' 34 39	36	(33) X (6) = SECONDS OF ARC (Sign always -) (-)	0 052
11°	TABULAR DIFFERENCE FOR 1 SECOND OPPOSITE TABULAR VALUE OF FUNCTION I IN (9)	30 801 91	37	ALGEBRAIC SUM (30), (33), AND (36) = SECONDS OF ARC (Sign always +) (+)	2 152 062
12°	TABULAR VALUE FUNCTION VII OPPOSITE LATITUDE IN (10)	1 757 762	38	CONVERT (37) TO DEGREES, MINUTES, SECONDS OF ARC	° ' " 0 35 52 062
13°	TABULAR DIFFERENCE FOR 1 SECOND OPPOSITE TABULAR VALUE OF FUNCTION VII IN (12)	0 018 12	39	LONGITUDE OF CENTRAL MERIDIAN OF UTM GRID ZONE BEING USED (Use table)	99° (EAST) WEST LONGITUDE
14°	TABULAR VALUE FUNCTION VIII OPPOSITE LATITUDE IN (10)	23 08	40	LONGITUDE OF STATION	98° 59' 60" 000
15°	GRAPHIC VALUE D_6 = SECONDS OF ARC [USE VALUE IN STEP 14 AS ARGUMENT. ENTER GRAPH AT LEFT SIDE (Sign always -)] (-)			IF (39) IS WEST LONGITUDE AND (1) IS LESS THAN (2), USE (38) + (39)	- 0 35 52 062
16	(8) - (9)	162 45		IF (39) IS WEST LONGITUDE AND (1) IS MORE THAN (2), USE (39) - (38)	
17	(16) ÷ (11)	5 274		IF (39) IS EAST LONGITUDE AND (1) IS LESS THAN (3), USE (39) - (38)	E (W)
18	(17) + (10) = APPROXIMATE LATITUDE OF STATION IN DEGREES, MINUTES, SECONDS	° ' " 34 39 05 274		IF (39) IS EAST LONGITUDE AND (1) IS MORE THAN (3), USE (38) + (39)	98 ° 24 ' 07 " 938
19	(13) X (17)	0 096			
20	(19) + (12)	1 757 858	* Obtained from UTM Grid Tables for spheroid being used, Volume II.		
21	(20) X (3) = SECONDS OF ARC	5 276			
22	CONVERT (21) TO MINUTES AND SECONDS OF ARC (Sign always -) (-)	' " 5 276	COMPUTER	SFC Kruck	
23	(7) X (14) = SECONDS OF ARC		CHECKER	SP/4 Barnett	
24	ALGEBRAIC SUM OF (13), (18), (22), AND (33) = LATITUDE OF STATION IN HEMISPHERE SHOWN ABOVE	(N) (S) ° ' " 34 38 59 998	DATE	19 November 1968	

DA FORM 1 OCT 83 6-22

REPLACES DA FORM 6-22, 1 SEP 82, EXISTING SUPPLIES OF WHICH WILL BE ISSUED AND USED UNTIL 1 OCT 84 UNLESS SOONER EXHAUSTED.

Figure 17-6. DA Form 6-22, computation—conversion UTM grid coordinates to geographic coordinates (machine).

ing a line horizontally to the right side of the nomogram for the B_5 value. Owing to the fact that it is a fifth order term, B_5 is totally insignificant at distances less than 1° from the central meridian.

c. Term Δ^2 IV. The Δ^2 IV graph (fig 17-3) is used when precise values of (IV) are desired. This graph takes into account the curvature of (IV), which is ignored in ordinary interpolation at the tabulated values of the main table. The figures in seconds at the left of the graph represent the seconds of latitude; the decimals at the right are in the same units as function (IV) in the tables. It is apparent on examining the tables that this function rises from 0 at 0 seconds to a maximum at 30 seconds, and then falls again to 0 at 60 seconds within each minute of latitude.

d. Tabular Value Functions I, II, III, IV and V. Functions I, II, III, IV and V, (fig 17-2 and 17-3) are tabulated in the main tables for each 1 minute of latitude. Opposite each tabular function is the tabulated difference for 1 second of latitude. These values can be read directly from the table for use in computations.

17-6. DA Forms for Conversion Computations

Conversion computations may be done without forms although the procedure is somewhat simplified by the use of forms. Available forms are DA Form 6-25 (Computations—Conversion Geographic Coordinates to UTM Grid Coordinates (Machine)), illustrated in figure 17-4; DA Form 6-23 (Computation—Conversion Geographic Coordinates to UTM Grid Coordinates (Logarithms)), illustrated in figure 17-5; and DA Form 6-22 (Computation—Conversion UTM Grid Coordinates to Geographic Coordinates (Machine)) (fig 17-6). Both DA Forms 6-25 and 6-23 are completed in numerical sequence, determining tabular values wherever indicated by the asterisks. The central meridian may be obtained from tables on the back of the forms if the UTM zone number is known, or it may be computed by using the following formulas:

CM (west longitude) = 183° — (zone number × 6°)
CM (east longitude) = (zone number × 6°) — 183°

Section II. TRANSFORMATION

17-7. Transformation of Universal Transverse Mercator Grid Coodinates From Zone to Zone

It is necessary to undertake transformations where combat areas embrace more than one grid zone. The most likely circumstances under which transformation might be accomplished would be when requirements exist to fire from one zone to another. In the universal transverse Mercator grid system, there are overlap areas east and west of zone junctions; however, transformation is not restricted to these overlap areas. Grid coordinates (and azimuths) can be transformed from any point in one zone into terms of an adjacent zone (fig 17-7).

Figure 17-7 shows two adjacent universal transverse Mercator zones, 14 and 15. In terms of northing coordinates, the zones are numbered the same since the origin of the northing coordinate is the Equator, however the easting coordinates from left to right are not a continuous series of numbers since the origin of the easting coordinate for each zone is the central meridian (CM) for that zone and is numbered 500,000. The coordinates increase to the east and decrease to the west from the central meridian. Visualize the point P located in the 14th zone. The coordinates shown for point P are (800,000-3,700,000). If the coordinates of point P were to be transformed to the adjacent grid (zone 15), the action taken would be the equivalent of superimposing the grid of zone 15 over the grid of zone 14 as indicated. Actually, transformation of coordinates involves only the mathematical continuation of the adjacent grid to the grid being used and the subsequent corrections for location due to the change in grid north reference. In figure 17-7, although the location of point P on the ground is unchanged, the value of the coordinates will change with transformation. The values in terms of zone 15 would be less than 100,000 meters in easting and greater than 3,700,000 in northing. From this figure it is obvious that in transforming coordinates there will be an appreciable change in easting coordinates due to the coordinate numbering system of each zone and the change in grid north reference, but there will be only a small change in northing coordinates, based only on the difference in the grid north reference.

17-8. Formulas Used in Transformation of Universal Transverse Mercator Coordinates

The transformation of grid coordinates involves the use of the following formulas and TM 5-241-2:

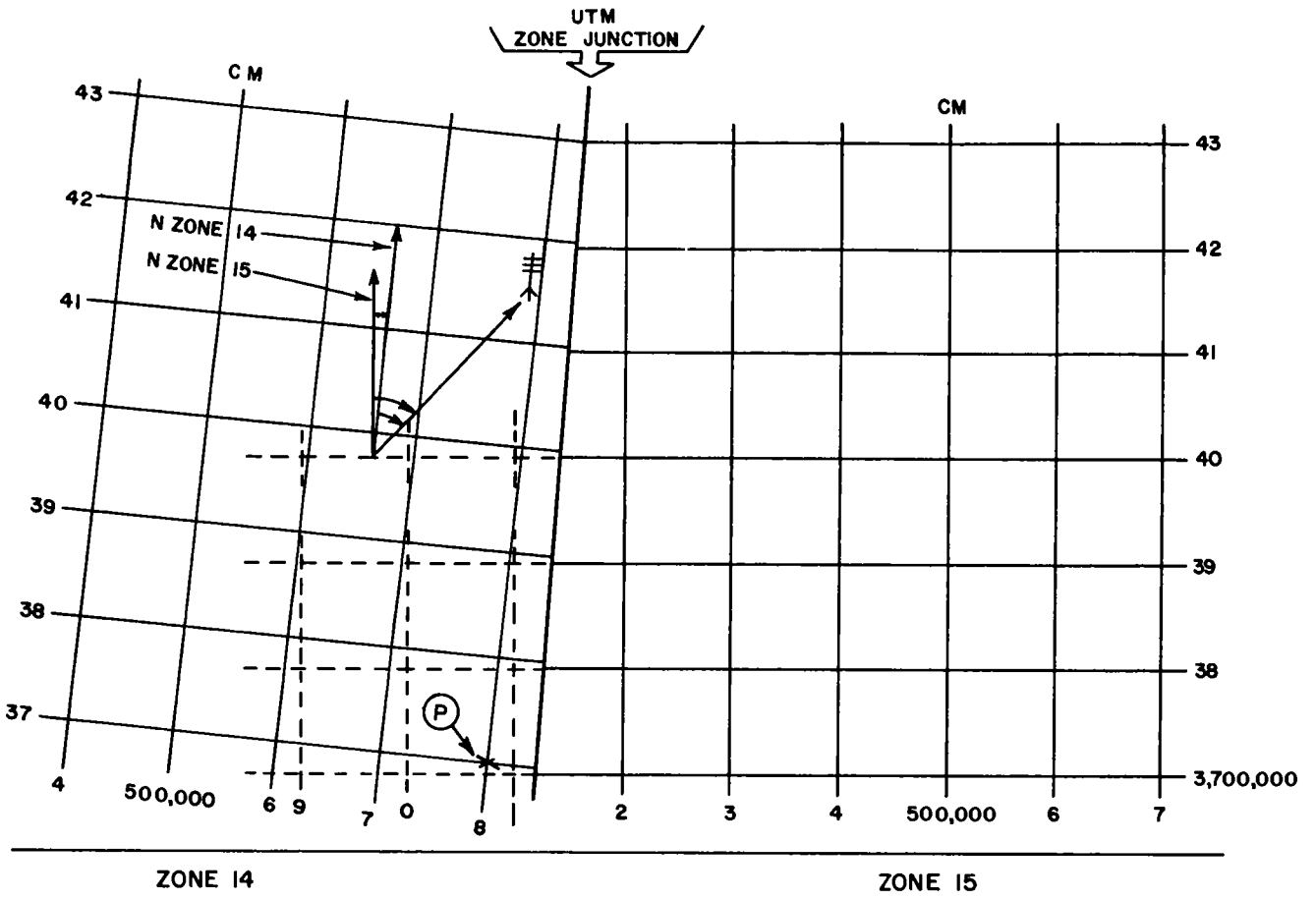


Figure 17-7. Schematic drawing illustrating transformation requirements.

$A = b_1 + n'c_4 - e'c_2$
$B = b_2 + n'c_3 + e'c_1$
$C = a_1 + n'A - e'B$
$D = a_2 + n'B + e'A$
$N = N_0 + n'C - e'D$
$E = 500{,}000 + E_0 + n'D + e'C$

Where A, B, C and D = Auxiliary terms to designate steps only.

N = Transformed northing coordinates.

E = Transformed easting coordinates.

n' = The difference between the northing to be transformed and the nearest 100,000-meter interval, with the decimal point moved left 5 places.

e' = The difference between the easting to be transformed and the nearest 100,000-meter interval, with the decimal point moved left 5 places.

All others = Functions extracted from table in Technical Manual 5-241-2 for proper spheroid using coordinates to the nearest 100,000-meter intervals as arguments.

17-9. Use of DA Form 6-36 (Zone to Zone UTM Grid Coordinates Transformation)

The use of forms will simplify transformation computations. The form used for zone to zone universal transverse Mercator grid coordinates transformation is DA Form 6-36 (fig 17-8. This form is designed for use with a computing machine. If a computing machine is not available, multiplications are performed on a separate paper by using logarithms or direct multiplication, and the results are entered in the proper spaces. The form is executed in a straight numerical sequence with the values in lines 11 through 18 (N_0, E_0, a_1, a_2, b_1, b_2, c_1, c_2) extracted from TM 5-241-2 for the proper spheroid.

17-10. Use of Technical Manual 5-241-2

Note. For a complete understanding of the following discussion, refer to TM 5-241-2.

a. In using TM 5-241-2 to extract the functions required for the formulas used in transformation, the spheroid to be used is determined first. This can be accomplished by referring to the map of the world found in the back of the manuals and using it as index to determine which spheroid tables should be used.

b. The tables in TM 5-241-2 are compiled for

ZONE TO ZONE UTM GRID COORDINATES TRANSFORMATION

For use of this form, see FM 6-2; the proponent agency is U.S. Continental Army Command.

STATION: SILL

LOCALITY: Ft. Sill, Oklahoma

FROM ZONE A: 14 TO ZONE B: 13

SPHEROID: CLARK 1866

1	E (Zone A)	+	556 139 87
2	(1) TO NEAREST 100,000 METERS (e)	−	600 000 00
3	ALGEBRAIC SUM (1) AND (2)	±	43 860 13
4	REPEAT (3) WITH DECIMAL POINT MOVED LEFT FIVE PLACES = e'	±	0 4386013

Enter DA Technical Manual 5-241-2 for proper spheroid using values from lines (2) and (8) as arguments. When transforming to east, use (e) value on right side of table and upper of signs; for transforming to west, use (e) value on left side of table and lower of signs.

5	USE ONLY FOR SOUTHERN HEMISPHERE		10 000 000 00
6	N (Zone A)	+	3 833 334 09
7	(S) − (6) FOR SOUTHERN HEMISPHERE	+	
8	(6) OR (7) TO NEAREST 100,000 METERS = (n)	−	3 800 000 00
9	ALGEBRAIC SUM (6) OR (7) AND (8)	⊕	33 334 09
10	REPEAT (9) WITH DECIMAL POINT MOVED LEFT FIVE PLACES = n'	⊕	0 3333409
11	N_0	+	3 822 297 707
12	E_0	⊕	652 499 349
13	a_1	+	100 336 277
14	a_2	±	5 958 532
15	b_1	−	8 904
16	b_2	±	68 056
17	c_1	±	0 037
18	c_2	⊕	0 261
19	(15)	−	8 904
20	(10) X (17)	±	0 012
21	ALGEBRAIC SUM (19) AND (20)	±	8 916
22	(4) X (18) CHANGE SIGN OF RESULT	⊕	0 114
23	ALGEBRAIC SUM (21) AND (22)	±	8 802
24	(16)	±	68 056
25	(10) X (18)	⊕	0 087
26	(4) X (17)	⊕	0 016
27	ALGEBRAIC SUM (24), (25), AND (26)	±	67 953
28	(13)	+	100 336 277
29	(10) X (23)	±	2 934
30	ALGEBRAIC SUM (28) AND (29)	⊕	100 333 343
31	(4) X (27) CHANGE SIGN OF RESULT	±	29 804
32	ALGEBRAIC SUM (30) AND (31)	+	100 303 539
33	(14)	±	5 958 532
34	(10) X (27)	±	22 652
35	(4) X (23)	⊕	3 861
36	ALGEBRAIC SUM (33), (34), AND (35)	±	5 977 323
37	FALSE EASTING	+	500 000 000
38	(12)	⊕	652 499 349
39	(10) X (36)	±	1 992 486
40	(4) X (32)	±	43 993 263
41	ALGEBRAIC SUM (37), (38), (39), AND (40) E (Zone B)	⊕	1 106 513 600
42	(11)	+	3 822 297 707
43	(10) X (32)	⊕	33 435 272
44	ALGEBRAIC SUM (42) AND (43)	⊕	3 855 732 979
45	(4) X (36) CHANGE SIGN OF RESULT	±	2 621 662
46	ALGEBRAIC SUM (44) AND (45) N (Zone B)	+	3 853 111 317
47	USE ONLY FOR SOUTHERN HEMISPHERE		10 000 000 00
48	REPEAT (46)		
49	(47) − (48) FOR SOUTHERN HEMISPHERE N (Zone B)	+	

COMPUTER: SGT J. White

CHECKER: PFC R. Dixon

DATE: 5 Oct 62

DA FORM 1 OCT 67 6-36 REPLACES EDITION OF 1 AUG 54, WHICH MAY BE USED.

Figure 17-8. Completed DA Form 6-36.

ZONE TO ZONE UTM GRID AZIMUTH TRANSFORMATION

For use of this form, see FM 6-2 and TM 5-241-2; the proponent agency is U.S. Continental Army Command.

STATION: SILL	LOCALITY: Ft. Sill, Oklahoma
FROM ZONE A: 14 TO ZONE B: 13	SPHEROID: CLARK 1866

1	AZIMUTH TO BE TRANSFORMED FROM ZONE A TO ZONE B = T_1	751 768	6	USE ONLY FOR SOUTHERN HEMISPHERE	10 000 000 00
2	E (Zone A) +	556 139 87	7	N (Zone A) +	3 833 334 09
3	(2) TO NEAREST 100,000 METERS = (e) −	600 000 00	8	(6) − (7) FOR SOUTHERN HEMISPHERE +	
4	ALGEBRAIC SUM (2) AND (3) + −	43 860 13	9	(7) OR (8) TO NEAREST 100,000 METERS = (n) −	3 800 000 00
5	REPEAT (4) WITH DECIMAL POINT MOVED LEFT FIVE PLACES = e' + −	0 43 860 13	10	ALGEBRAIC SUM (7) OR (8) AND (9) + −	33 334 09
	Enter DA Technical Manual 5-241-2 for proper spheroid using values from Lines (3) and (9) as arguments. When transforming to east, use (e) value on right side of table and upper of signs; for transforming to west, use (e) value on left side of table and lower of signs.		11	REPEAT (10) WITH DECIMAL POINT MOVED LEFT FIVE PLACES = n' + −	0 33 334 09
			12	a_1 +	100 336 277
			13	a_2 ±	5 958 532
			14	b_1 −	08 904
			15	b_2 ±	68 056
			16	c_1 + −	0 037
			17	c_2 + −	0 261
18	(14) X 2 −	17 808	32	(13) ±	5 958 532
19	(11) X (16) X 3 + −	037	33	(11) X (26) + −	45 268
20	ALGEBRAIC SUM (18) AND (19) −	17 845	34	(5) X (22) + −	7 676
21	(5) X (17) X 3 CHANGE SIGN OF RESULT + −	343	35	ALGEBRAIC SUM (32), (33), AND (34) + −	5 996 124
22	ALGEBRAIC SUM (20) AND (21) −	17 502	36		10 000 0000
23	(15) X 2 ±	136 112	37	LOG (31)	5 001 1748
24	(11) X (17) X 3 + −	261	38	(36) − (37)	4 998 8252
25	(5) X (16) X 3 + −	049	39	LOG (35)	3 777 8706
26	ALGEBRAIC SUM (23), (24), AND (25) + −	135 802	40	(38) + (39)	8 776 6958
27	(12) +	100 336 277	41	ANGLE WHOSE LOG TAN IS (40), USE SIGN OF (35) ±	60 . 839
28	(11) X (22) ±	5 834	42	(1) +	751 . 768
29	ALGEBRAIC SUM (27) AND (28) +	100 330 443	43	REPEAT (41), CHANGE SIGN FOR SOUTHERN HEMISPHERE ±	60 . 839
30	(5) X (26) CHANGE SIGN OF RESULT + −	59 563	44	ALGEBRAIC SUM (42) AND (43) AZIMUTH (Zone B)	690 . 929
31	ALGEBRAIC SUM (29) AND (30) +	100 270 880			

COMPUTER	CHECKER	DATE
WEST	LANGLAND	18 Sept 67

DA FORM 1 MAY 68 6-34 REPLACES EDITION OF 1 DEC 63, WHICH WILL BE USED.

Figure 17-9. Completed DA Form 6-34

100,000-meter intervals of easting and northing. A station is considered to be in a 100,000-meter square, and the coordinates of the nearest corner of this square are used for the determination of e′ and n′ and for the entering arguments.

c. Certain procedures must be followed to insure proper extraction from the tables. These procedures are as follows:

(1) When transforming to the east (such as zone 14 to 15), use the e value on the right side of the table and the upper sign where there are two shown.

(2) When transforming to the west (such as zone 15 to zone 14), use the value on the left side of the table and the lower sign.

d. In performing the computations on DA Form 6–36 and considering the initial zone to be A, the resulting E and N coordinates are for the adjacent zone, B. In the Southern Hemisphere the transformed northing must be subtracted from 10,000,000 to get the correct coordinate.

17–11. Transformation of Universal Transverse Mercator Grid Azimuth From Zone to Zone

The same reasons for transforming grid coordinates (para 17–7) are applicable to grid azimuths and the same reference tables, TM 5–241–2, are employed for the extraction of functions. To understand what transpires when transformation of azimuth takes place, refer to figure 17–7. On the universal transverse Mercator zone to the left (zone 14), a line of direction has been indicated. The azimuth of this line is represented by a horizontal clockwise angle from the grid north for zone 14. If the azimuth of that line is transformed to the grid of the adjacent zone (zone 15) the line of direction does not change; however, due to a new grid north reference line, the azimuth of the line will increase. From this figure, in transforming azimuth from west zone to an east zone, the azimuth will increase; conversely, in transforming azimuth from an east zone to a west zone, azimuth will decrease.

17–12. Formulas Used in Transformation of Universal Transverse Mercator Grid Azimuths

The transformation of grid azimuth involves the use of the following formulas and TM 5–241–2:

$$F = 2b_1 + 3n'c_1 - 3e'c_2$$

$$G = 2b_2 + 3n'c_2 + 3e'c_1$$

$$A_1 = a_2 + n'F - e'G$$

$$A_2 = a_2 + n'G + e'F$$

$$\text{Tan } t = \frac{A_2}{A_1} \text{ (in Northern Hemisphere}$$

$$\tan t = -\frac{A_2}{A_1} \text{ (in Southern Hemisphere)}$$

$$T_2 = T_1 + t$$

There, F, G, A_1, and A_2 = Auxiliary terms to designate steps only.

t = Transformation correction.

T_1 = The grid azimuth of a line from some known station to some other station or point referred to grid north of the initial zone, A.

T_2 = The grid azimuth of this same line (T_1) referred to grid north of an adjacent zone, B.

All others = The same as explained for coordinates transformation.

17–13. Use of DA Form 6–34 (Zone to Zone UTM Grid Azimuth Transformation)

The form used for zone to zone universal traverse Mercator grid azimuth transformation is DA Form 6–34 (fig 17–9). This form, which is similar to DA Form 6–36, also was designed for computing with a machine. Values for a_1, a_2, b_1, b_2, c_1, and c_2 are extracted directly from TM 5–241–2.

CHAPTER 18
QUALIFICATION TESTS FOR SURVEY SPECIALISTS

18–1. Purpose and Scope

This chapter describes the tests to be given in the qualification of survey specialists at all echelons. Tests based on these outlines are designed to measure a soldier's skill in field artillery survey. School training or a technical background is not required prior to taking these tests. Tests based on these outlines are designed to determine the relative proficiency of an individual field artillery soldier in the performance of duties as a member of a survey section and are not designed as a basis for determining the relative proficiency of batteries or higher units. These tests are also designed to serve as an incentive for individuals in survey organizations to expand their knowledge to cover all duties in the survey organization, thereby increasing their value to the unit.

18–2. Preparation of Tests

The tests will be prepared under the direction of the battalion commander, and should consider the following:

a. Tests should be standardized so that the difference between the test scores of any two individuals will be a valid measurement of differences in their skills.

b. Each crewman interested is a prospective candidate and the tests should be available upon his request.

18–3. Test Organization

The qualification test is organized into three sections with each section designed to test and qualify the individual progressively as a second-class specialist, a first-class specialist and as an expert in field artillery survey. Section I is designed to evaluate the qualification of the individual in the basic skills of a field artillery surveyor. Section II expands the skill coverage for evaluating the qualifications of an individual in field artillery survey. Section III is designed as a comprehensive coverage of the skills required in all echelons of field artillery survey.

18–4. Administration of Tests

a. The tests based on these outlines are designed to provide for qualification of survey specialists at all echelons. Because of organizational differences and differences in equipment, some modification will be necessary for the administration of these tests to most units. The tests are designed where possible to facilitate this modification. Modification other that those options presented in the tests should be accompanied by a reevaluation of the weighting system.

b. The battery commander will be responsible for the testing of personnel within his battery. Generally, tests will be administered as follows:

(1) An officer, warrant officer, or enlisted man who is fully qualified and experienced in the subject covered by the test will be detailed as "examiner" to administer the test.

(2) Each section of the qualification tests may be administered over a period of time that will be standardized throughout the battalion.

(3) A single test, when started, will be conducted from start to finish without interruption.

(4) The candidate will receive no unauthorized assistance. Assistance will be furnished to the candidate as required for each test. If a candidate fails any test because of the examiner or any assistant, the test will be disregarded and the candidate will be given another test of the same nature.

(5) Times are not prescribed for tests due to the different requirements of units and because of varying effects of weather on the tests. However, the examiner should make appropriate cuts when "excessive time" is taken to complete a portion of the tests. A decision by the responsible officer as to what constitutes "excessive time" must be made prior to the administration of the tests, based on conditions existing at that time.

(6) The examiner will explain to the candidate the scope of the test and indicate the men who will act as his assistants. The examiner will critique the candidate's performance at the completion of the test and turn the tentative score in to the battery commander. The battery commander will finalize the score and forward the test score to the battalion.

18–5. Qualification Score

A maximum score of 100 is possible for each section of the test. An individual must achieve a score of 90 percent in section I to be eligible to take section II. A score of 90 percent on section II is required prior to taking section III.

Individual Classification	*Points*
Expert	90 on section III
First-class specialist	85 on section II
Second-class specialist	85 on section I

Note. A score of zero on any paragraph of a section disqualifies the candidate at that level.

18–6. Outline of Tests

Para number	Subject	Number of tests		Points each		Maximum credit
	SECTION I					
18–7	Map Reading	4		–		6
	Tests 1 and 2	(2)		2		(4)
	Tests 3 and 4	(2)		1		(2)
18–8	Recording	2		11		22
18–9	Computing	4		–		28
	Tests 1 and 4	(2)		5		(10)
	Test 2	(1)		8		(8)
	Test 3	(1)		10		(10)
18–10	Taping	1		20		20
18–11	Instrument Operation	2		12		24
	Total	–		–		100
	SECTION II					
	Section I score × .40	–		–		40
18–12	Recording	2		10		20
18–13	Computations	3		–		20
	Tests 1 and 2	(2)		7		(14)
	Test 3	(1)		6		(6)
18–14	Instrument operation	3		–		20
	Test 1*	(1)		8		(8)
	Test 2	(1)	*8	(12)	*(8)	(12)
	Test 3	(1)	*4	(8)	*(4)	(8)
	*When tellurometer or DME is not issued to a unit Test 1 will be disregarded and point value of Test 1 will be redistributed as follows: Test 2, 12 points; Test 3, 8 points.					
	Total	–		–		100
	SECTION III					
	Section II total × .50	–		–		50
18–15	Map Reading	1		–		5
18–16	Grid Computations	3		–		10
	Tests 1 and 2	(2)		4		(8)
	Test 3	(1)		2		(2)
18–17	Survey Planning	1		15		15
18–18	Supervision and Operation	1		20		20
	Total	–		–		100

SECTION I

18–7. Map Reading

a. Scope of Tests. Four tests will be conducted to determine the candidate's knowledge of map reading:

b. Special Instructions. Prior to the start of the test the examiner will provide the candidates with the following equipment:

(1) Topographic map, scale 1:50,000 or larger.
(2) Boxwood scale or coordinate scale, protractor and map pins.
(3) Military slide rule (if desired by candidate).

c. Outline of Tests.

Test number	Examiner commands—	Action of candidate
1	IDENTIFY THESE SIGNS AND SYMBOLS. (Examiner points to 10 different commonly used military and topographic signs and symbols.)	Identifies signs and symbols as they are pointed out, orally or by writing answer.
2	COMPUTE THE SCALE OF THIS MAP. (Examiner designates two points on the map at least four inches apart, and gives the candidate a false ground distance between them.)	Measures the map distance between the two points. Computes the scale using the map distance and the false ground distance. Announces or records the result.
3	MEASURE THE GRID AZIMUTH FROM_____TO_____ (Examiner points out two prominent points on map at least four inches apart.)	Measures the grid azimuth with the protractor. Announces or records results.
4	DETERMINE COORDINATES AND HEIGHT OF _____ (Examiner points out or designates arbitrary feature on map. Advise candidate to read coordinates and height as accurately as possible.)	Reads coordinates of designated point and determines height. Announces or records results.

d. Penalties.

(1) *Test 1.* Deduct 0.2 point for each symbol or sign identified incorrectly.

(2) *Test 2.* Deduct 1 point if the denominator of the representative fraction is in error by more than 100 units and deduct all credit if in error by more than 200 units.

(3) *Test 3.* Deduct 0.5 point if the azimuth is in error by more than 5 mils and 1 point if in error by over 10 mils.

(4) *Test 4.*

(*a*) Deduct 0.6 point if either the easting or northing coordinate is in error by over 50 meters.

(*b*) Deduct 0.4 point if the height is in error by more than one-half of the contour interval of the map.

e. Credit. Subject to the penalities assessed in *d* above, credit will be awarded as indicated in paragraph 18–6.

18–8. Recording

a. Scope of Test. Two tests will be conducted to determine the candidate's knowledge of recording. The first test will check procedures used with the aiming circle and the second test will be on procedures for the basic survey instrument authorized by TOE.

b. Special Instructions. Prior to the start of the test the examiner will make the following preparations:

(1) Provide equipment as listed below.

(*a*) Blank mimeographed sheets from recorder's notebook.

(*b*) 4H and 6H pencil.

(*c*) Straightedge.

(2) Prepare the data so the examiner can read angles and distances, etc., in the same manner as a recorder would receive the data if he were accompanying a survey team in the field. Prepare a rough sketch of the area to permit the candidate to complete the remarks and sketch portion of the field notes.

c. Outline of Tests.

Test number	Examiner commands—	Action of candidate
1	RECORD DATA FOR AIMING CIRCLE TRAVERSE. (Examiner reads data in same manner as normally available to recorder.)	Records data as prescribed in chapter 8. Turns in field notes to examiner at completion of the test.
2	RECORD DATA FOR THEODOLITE TRAVERSE. (Examiner reads data in same manner as normally available to recorder. Include at least one multiple angle. Triangulation or astronomic observation are authorized substitutions.)	Records data as prescribed in chapter 8. Turns in field notes to examiner at completion of the test.

d. Penalties. Penalties will be assessed as follows:

(1) Failure to use proper procedure for recording horizontal or vertical angles, 3 points.

(2) Failure to mean angles correctly, 3 points.

(3) Incomplete or incorrect remarks section, 1 point.

(4) Failure to record data in a neat and legible manner, 10 points.

(5) Any other procedural error, 3 points.

e. Credit. Subject to the penalties assessed in *d* above, credit will be awarded as indicated in paragraph 18–6. Maximum deduction will not exceed maximum allowable credit for test.

18–9. Computing

a. Scope of Tests. Four tests will be conducted to determine the candidate's knowledge and ability to solve various survey problems.

b. Special Instructions. Prior to the start of the tests the examiner will make the following preparations:

(1) Provide the following equipment:

(*a*) One set of logarithmic tables (six or seven-place as appropriate) for each candidate.

(*b*) DA Forms 6–1, 6–2, 6–8 and 6–19.

(2) Prepare simulated or actual field data for all tests in the format prescribed for the recorder's field notebook. Read or issue copy of data to the candidate.

c. Outline of Tests.

Test number	Examiner commands—	Action of candidate
1	COMPUTE THE AZIMUTH AND DISTANCE FROM POINT A TO POINT B. (Furnish coordinates of each point).	Computes azimuth and distance with DA Form 6–1.
2	COMPUTE THE FOLLOWING TRAVERSE: COMPUTE ACCURACY RATIO AND AZIMUTH ERROR OF CLOSURE. (Provide coordinates of starting point and azimuth to azimuth mark. Furnish angles and distance in the same manner in which a computer would normally receive this information. Provide coordinates of closing point and azimuth to azimuth mark if different than starting point).	Computes coordinates of each station on DA Form 6–2. Computes accuracy ratio; azimuth error of closure.
3	COMPUTE THE FOLLOWING TRIANGLE CHAIN. (Provide starting data and simulated or actual field work to enable candidate to solve the triangulation problem. Data should be made available in the same sequence as normally provided to the computer by a survey party in the field.)	Uses field data provided and DA Form 6–8 to solve triangle chain.
4	COMPUTE THE FOLLOWING THREE-POINT RESECTION TO DETERMINE COORDINATES AND HEIGHT OF THE OCCUPIED STATION. (Provide candidate with necessary valid field data to perform the computation.)	Records field data on DA Form 6–19 and computes coordinates and height of occupied station.

d. Penalties.

(1) *Tests 1 and 3.* Deduct—

(*a*) 0.5 point for each mathematical error.

(*b*) 1.0 point for each logarithmic error.

(*c*) 3.0 points for each procedural error.

(2) *Test 2.* Deduct—

(*a*) 0.5 points for each mathematical error.

(*b*). 1.0 point for each logarithmic error.

(*c*) 3.0 points for each procedural error.

(*d*) 1.0 point if accuracy ratio is computed incorrectly and 0.5 point if the azimuth error of closure is computed incorrectly.

(3) *Test 4.* Deduct—

(*a*) 0.5 point for each mathematical error.

(*b*) 1.0 point for each logarithmic error.

(*c*) 1.0 point for each procedural error.

e. Credit. Subject to the penalties assessed in *d* above, credit will be awarded as indicated in paragraph 18–6. Dduction will not exceed maximum allowable credit for test.

78–10. Taping

a. Scope of Test. One test will be conducted to determine the candidate's ability to function as a tapeman.

b. Special Instructions. Prior to the start of the test the examiner will make the following preparations:

(1) Provide equipment as listed below:

(*a*) One 30-meter steel tape.
(*b*) Two plumb bobs.
(*c*) One set of eleven taping arrows.
(*d*) Two taping knuckles.
(*e*) One handle, steel tape, tension 30 lbs.
(*f*) Two ranging poles w/tripods.

(2) Prepare a traverse course consisting of two stations, A and B. Determine the accurate distance between the two. Use terrain that will require breaking tape. Require candidate to tape both ways but change position from front tapeman to rear tapeman on the return run. Use a second candidate or assistant examiner for the second tapeman.

c. Outline of test.

Examiner commands—	Action of candidate
TAPE TRAVERSE LEG FROM *A* to *B* AND FROM *B* TO *A*, TO A COMPARATIVE ACCURACY OF 1:5000. COMPUTE COMPARATIVE ACCURACY OF THE TWO TAPED DISTANCES.	Tapes traverse leg as prescribed in chapter 6. Computes comparative accuracy.

d. Penalties. A penalty of 3.0 points will be assessed for each of the following errors:

(1) Failure to maintain tape tension.
(2) Failure to maintain the tape in a horizontal position.
(3) Improper handling of the plumb bob.
(4) Failure to aline front tapeman.
(5) Errors in breaking tape.
(6) Errors in recording distance.
(7) Incorrect computation of accuracy ratio.
(8) Accuracy ratio below 1:5000. Accuracy ratio below 1:3000, cut 10 points.
(9) Any other procedural error.

e. Credit. Subject to the penalties assessed in *d* above, credit will be awarded as indicated in paragraph 18–6. Deduction will not exceed maximum allowable credit for test.

18–11. Instrument Operation

a. Scope of Test. Two tests will be conducted to determine the candidate's ability to set up and operate an aiming circle and the theodolite.

b. Special Instructions. Prior to the start of the test the examiner will make the following preparations:

(1) Provide equipment as listed below:

(*a*) Aiming circle w/tripod.
(*b*) Theodolite w/tripod.

(2) Prepare the stations as necessary and accurately determine angles, distances, azimuths, etc., to be used as a check on accuracy. Provide an assistant examiner as recorder for all tests.

c. Outline of Tests.

Test number	Examiner commands—	Action of candidate
1	MEASURE THE HORIZONTAL AND VERTICAL ANGLES AZ MK-Bn SCP-TS 1 WITH THE AIMING CIRCLE. (Designate the Bn SCP and identify the Az Mk and TS 1.)	Sets up aiming circle and measures horizontal and vertical angles and announces the results
2	MEASURE THE HORIZONTAL AND VERTICAL ANGLES TS1–TS2–TS3 WITH THE THEODOLITE. (Designate TS 2 as the occupied station of a traverse and identify the rear and forward stations.)	Sets up the theodolite and measures horizontal and vertical angles as prescribed in chapter 7. Means the angles and announces the results.

d. Penalties.

(1) *Test 1.* Deduct—

(*a*) 3.0 points for improper setup, leveling or handling of the instrument.

(*b*) 2.0 points for each procedural error in the angle measurement.

(*c*) 4.0 points if the horizontal or vertical angle is in error by more than 1.0 mil but less than 2.0 mils.

(*d*) 6.0 points if the horizontal or vertical angle is in error by more than 2.0 mils.

(2) *Test 2.*

(*a*) Deduct 3.0 points for improper set up, leveling or handling of the instrument.

(*b*) Deduct 2.0 points for each procedural error in the angle measurement.

(*c*) For accuracy of measurement of horizontal and vertical angles, cut as indicated:

0.2 mil Theodolite	*1 sec. Theodolite (Sexagesimal)*	*0.002 mil Theodolite*	*Cut*
Less than 0.1 mil	Less than 05"	Less than 0.02 mil	0.0
0.1–0.2 mil	05"–15"	0.02–0.08 mil	3.0
More than 0.2 mil	More than 15"	More than 0.08 mil	6.0

e. Credits. Subject to the penalties assessed in *d* above, credit will be awarded as indicated in paragraph 18–6. Deduction will not exceed maximum allowable credit for test.

SECTION II

(Consists of 40 percent of the earned score from section I plus the score earned in paragraphs 18–12 and 18–14.

18–12. Recording

a. Scope of Tests. Two tests will be conducted to determine the candidate's ability to record triangulation field notes and an astronomic observation problem.

b. Special Instructions. Prior to the start of the test the examiner will make the following preparations:

(1) Provide equipment as listed below:

(*a*) Field notebook or mimeographed pages.

(*b*) 4H and 6H pencil.

(*c*) Straightedge.

(2) Prepare simulated or actual field data to present to candidate in the same manner as a recorder would normally receive this information.

c. Outline of Tests.

Test number	Examiner commands—	Action of candidate
1	RECORD THE FOLLOWING TRIANGULATION SURVEY. (Present field data from triangulation problem in the same sequence a recorder would normally receive this data.)	Records survey field data as prescribed in chapter 8.
2	RECORD THE FOLLOWING ASTRONOMIC OBSERVATION. (Present field data from the observation in the same sequence that a recorder would normally receive the data.)	Records field data from the astronomic observation as prescribed in chapter 8.

d. Penalties. Deduct—

(1) 2.0 points for each angle or time meaned incorrectly.

(2) 4.0 points for each procedural error.

(3) 4.0 points if field notes are not neat and legible.

e. Credit. Subject to the penalties assessed in *d* above, credit will be awarded as indicated in paragraph 18–6. Deduction will not exceed maximum allowable credit for test.

18–13. Computing

a. Scope of Tests. Three tests will be conducted to determine the candidate's ability as a computer. The first test is solving a triangle by trilateration and the second is computing an azimuth from an astronomic observation. The third test is computing grid convergence for a specific area.

b. Special Instructions.

(1) Provide equipment as listed below:

(*a*) Logarithmic tables (seven places).

(*b*) TM 6–300—(current year).

(*c*) DA Forms 6–7a, 6–10, 6–10a or 6–11, and 6–20.

(2) Prepare actual or simulated field data for each test.

c. Outline of Tests.

Test number	Examiner commands—	Action of candidate
1	SOLVE THE FOLLOWING TRIANGLE BY TRILATERATION. THE KNOWN LENGTH OF THE SIDES ARE: a. _____ b. _____ c. _____ DETERMINE THE SIZE OF EACH ANGLE.	Records given data on DA Form 6–7a and solves for interior angles.

Test number	Examiner commands—	Action of candidate
2	COMPUTE GRID AZIMUTH BY ASTRONOMIC OBSERVATION BY THE ALTITUDE (HOUR ANGLE) METHOD OF THE SUN (STAR). (Provide data from three sets of observations. Furnish grid convergence to permit candidate to determine grid azimuth.)	Uses field data provided and DA Forms 6-10, 6-10a or 6-11, and 6-20. Computes all three sets, mean sets and rejects any set that varies from the mean by more than the tolerance prescribed in chapter 14. Applies grid convergence to mean of at least two sets to get grid azimuth.
3	COMPUTE GRID CONVERGENCE GIVEN DATA: STATION: Bn SCP LATITUDE: _____N(S) LONGITUDE: _____E(W) COORDINATES: _____	Computes grid convergence. Uses DA Form 6-20 and TM 6-300-current year.

d. Penalties. Deduct 0.5 point for each mathematical error, 2.0 points for each logarithmic error and 4.0 points for each procedural error.

e. Credit. Subject to the penalties assessed in *d* above, credit will be awarded as indicated in paragraph 18-6. Deduction will not exceed maximum allowable credit for test.

18-14. Instrument Operation

a. Scope of Tests. Three tests will be conducted to determine the candidate's ability to operate the tellurometer or DME and the surveying instrument azimuth gyro and one test will be conducted to determine the candidate's ability to perform theodolite adjustments. Units not issued the tellurometer or DME will disregard Test 1.

b. Special Instructions. Prior to the start of the test the examiner will make the following preparations.

(1) Provide equipment as listed below:

(*a*) One master and one remote tellurometer unit or two DME units complete with cables, tripods and batteries.

(*b*) One surveying Instrument Azimuth Gyro Artillery complete with control panel and power source.

(*c*) One theodolite with tripod.

(*d*) DA Form 5-139 (Field Record and Computations—Tellurometer) or DA Form 2972 (Field Record and Computations—DME).

(*e*) Logarithmic tables (7 places)

(2) Provide as assistant examiner to operate the remote or responder unit.

(3) Provide a recorder for tests 1 and 2.

(4) Provide stations and azimuth marks as necessary to conduct tests 1 and 2.

c. Outline of Tests.

Test number	Examiner commands—	Action of candidate
1	MEASURE THE DISTANCE TS 2-TS3 WITH THE TELLUROMETER OR DME. (Stations must be at least 152 meters apart. Require the candidate to operate master station or measurer and instruct remote operator. Remote or responder operator can be another candidate or an assistant examiner. Delete this test for units not issued the tellurometer or DME. Redistribute credit to other two tests.)	Sets up the master or measurer unit; instructs remote or responder operator; measures distance. Resolves transit time and determines sea level distance in meters using DA Form 5-139, or DA Form 2972.
2	DETERMINE AZIMUTH TO AZIMUTH MARK WITH THE SURVEYING INSTRUMENT AZIMUTH GYRO ARTILLERY. (Identify orienting station and azimuth mark. Provide grid convergence to candidate. Determination of azimuth of astronomic observation in an authorized substitution.)	Sets up azimuth gyro and determines azimuth to azimuth mark. Applies grid conververgence to attain grid azimuth.
3	PERFORM THE FOLLOWING TESTS AND ADJUSTMENTS ON THE THEODOLITE: a. PLATE LEVEL. b. OPTICAL PLUMB. c. VERTICALITY (NOT APPLICABLE ON 0.2 MIL THEODOLITE). d. HORIZONTAL COLLIMATION. e. VERTICAL COLLIMATION.	Performs tests and adjusts as prescribed in chapter 7.

d. Penalties.

(1) *Test 1.* Deduct—

(*a*) 2 points for improper setup or handling of the instrument.

(*b*) 1 point if instructions by candidate to remote operator prior to beginning the measurement are inadequate.

(*c*) 3 points for each procedural error in the measurement.

(*d*) 2 points for each procedural error in the computation.

(*e*) 0.5 point for each mathematical error in the computation.

(*f*) 3 points if the accuracy is less than 1:7000 but more than 1:5000 when compared to the previously determined distance.

(*g*) 6 points if the accuracy is less than 1:5000 when compared to the previously determined distance.

(2) *Test 2.*

(*a*) Deduct 2 (3) points for improper setup, leveling or handling of the instrument.

(*b*) Deduct 3 (4) points for each procedural error in the azimuth measurement.

(*c*) Deduct 1 (2) point for each computational error.

(*d*) Deduct 6 (8) points if accuracy normally required by candidate's unit is not attained. (Specifications for accuracies are the same as listed in chapter 14 for astronomic observations.)

(*e*) The penalty points in parentheses in (*a*) through (*d*) above will be applied when Test Number 1 is not given.

(3) *Test 3.*

(*a*) Deduct 1 (2) point for each test or adjustment that is not conducted as prescribed in chapter 7.

(*b*) Deduct 1 (2) point if test and adjustments are not conducted in the sequence specified in chapter 7 for the instrument used.

(*c*) The penalty points in parentheses in (*a*) and (*b*) above will be applied when Test 1 is not given.

e. Credit. Subject to the penalties assessed in *d* above, credit will be awarded as indicated in paragraph 18–6. Deductions will not exceed maximum allowable credit for test.

SECTION III

(Consists of 50 percent of the earned score from section II plus the score earned in paragraphs 18–15 and 18–18).

18–15. Map Reading

a. Scope of Tests. One test will be conducted to determine the candidate's ability to scale geographic coordinates from a map.

b. Special Instructions. Prior to the start of the tests the examiner will make the following preparations and provide equipment listed below:

(1) Map 1:50,000 or larger.

(2) Straightedge.

(3) Military slide rule (if desired by candidate).

c. Outline of Test.

Test number	Examiner commands—	Action of candidate
1	DETERMINE THE GEOGRAPHIC COORDINATES OF _____ TO THE NEAREST 30 SECONDS.	Determine geographic coordinates of designated point.

d. Penalties. Deduct—

(1) 2 points if easting or northing is in error by more than 30 seconds but less than 60 seconds.

(2) All credit if easting or northing is in error by more than 60 seconds.

e. Credit. Subject to the penalties assessed in *d* above, credit will be awarded as indicated in paragraph 18–6.

18–16. Grid Computations

a. Scope of Tests. Three tests will be conducted to determine the candidate's knowledge of detailed survey computations consisting of converting geographic coordinates to grid coordinates, zone to zone transformation, and conversion to common control.

b. Special instructions. Prior to the start of the test the examiner will make the following preparations:

(1) Provide equipment as listed below

(*a*) TM 5-241 (as appropriate depending on spheroid involved).

(*b*) DA Forms 6-1, 6-2, 6-23, 6-34 and 6-36.

(*c*) Logarithmic tables (six- or seven-place).

(*d*) TM 5-241-2.

(2) Prepare realistic requirements to issue as tests 1-3. Solve and check requirements.

c. Outline of Tests.

Test number	Examiner commands—	Action of candidate
1	CONVERT THE FOLLOWING GEOGRAPHIC COORDINATES TO GRID COORDINATES: _____°_____'_____"N (S) _____°_____'_____"E (W)	Converts geographic coordinates to grid. Uses DA Form 6-25 and TM 5-241-(3/1, 4/1, 5/1, 6/1 and 7).
2	TRANSFORM THE FOLLOWING COORDINATES FROM ZONE _____TO ZONE_____: E _____ N _____.	Converts coordinates from one zone to the other. Uses DA Form 6-36 and TM 5-241-2
3	CONVERT THE FOLLOWING TRAVERSE TO THE COMMON GRID: ASSUMED DATA: COORDINATES BN SCP _____ _____ HEIGHT BN SCP _____ AZIMUTH TO AZIMUTH MARK _____ KNOWN DATA (COMMON GRID): COORDINATES BN SCP _____ HEIGHT BN SCP _____ AZIMUTH TO AZIMUTH MARK _____ (Require candidate to convert all or selected points of the traverse run with assumed data to the common grid.)	Converts designated points of traverse to common grid. DA Forms 6-1 and 6-2.

d. Penalties.

(1) *Tests 1 and 2.* Deduct 0.2 point for each mathematical error, 1 point for each logarithmic error and 2 points for each procedural error.

(2) *Test 3.* Deduct 0.2 point for each mathematical error, 0.4 point each logarithmic error and 0.5 point for each procedural error.

e. Credit. Subject to the penalties assessed in *d* above, credit will be awarded as indicated in paragraph 18-6. Deductions will not exceed maximum allowable credit for test.

18-17. Survey Planning

a. Scope of Test. One practical test will be conducted to determine the candidate's ability to plan a survey. This test will include a briefing by the examined, map reconnaissance, ground reconaissance, and the survey order.

b. Special Instructions. Prior to the start of the test, the examiner will make the following preparations:

(1) Provide an area in which a survey can be conducted.

(2) Provide a 1:50,000 map of the area.

(3) Prepare a situation to include unit mission, time available, designation and general location of points to be surveyed and restrictions on use of routes, transportation and radios.

(4) Provide a vehicle and driver for the candidate.

c. Outline of Test.

Examiner commands	Action of candidate
PREPARE A SURVEY PLAN TO SUPPORT THE UNIT'S MISSION. THE MISSION ASSIGNED IS AS FOLLOWS: _____ _____	Makes a map reconnaissance to include plotting installations requiring control.
EXTEND SURVEY CONTROL TO THE FOLLOWING POINTS: _____ _____ _____ _____ _____ YOU WILL HAVE _____ HOURS TO COMPLETE THE SURVEY. THE FOLLOWING RESTRICTIONS ARE IN FORCE: _____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____	Makes a detailed ground reconnaissance and formulates a plan. Issues a survey order to the survey party (examiner).

d. Penalties. Deduct—

(1) 2 points if the survey plan is not simple, timely or flexible.

(2) 5 points if the plan is not adaptable or if it does not provide for checks.

(3) 10 points if the plan cannot provide survey control to the required accuracy at all installations which require survey.

(4) 5 points if the survey order is not adequate to insure the mission is accomplished.

(5) 3 points if equipment is not utilized to best advantage.

e. Credit. Subject to the penalties assessed in *d* above, credit will be awarded as indicated in paragraph 18–6. Deductions will not exceed maximum allowable credit for test.

18–18. Supervision and Operation

a. Scope of Test. The test will determine the candidate's ability to organize and direct a survey party.

b. Special Instructions. Prior to the start of the test the examiner will provide a survey party complete with equipment and personnel authorized by applicable TOE.

c. Outline of Test.

Examiner Commands	Action of candidate
ORGANIZE THE SURVEY PARTY AND EXECUTE THE PLANNED SURVEY. (After the survey has started require the candidate to operate the instrument for at least one station.)	Briefs members of the survey party. Directs and supervises operation until completion. Functions as instrument operator when directed.

d. Penalties.

(1) Deduct 2 points for any failure to—

(*a*) Orient all personnel.

(*b*) Initiate the survey as soon as possible.

(*c*) Display an aggressive attitude in supervising the party while the survey is in progress.

(2) Deduct 3 points if the instrument is not set up, leveled and angles measured as prescribed in chapter 7. (Applicable only when the candidate is functioning as instrument operator).

(3) Deduct 3 points for each failure to—

(*a*) Provide computers with necessary data to begin computations.

(*b*) Properly select traverse (triangulation) stations.

(*c*) Supervise the work of the computers by spot checking their azimuths, bearing angles, distances and coordinates.

(*d*) Periodically verify the recorder's notes.

(*e*) Check taping procedures.

(*f*) Correct erratic procedures immediately on discovery.

(*g*) Check results by plotting surveyed points on a map.

(*h*) Supervise the instrument operator during theodolite, tellurometer, or surveying instrument azimuth gyro artillery operations.

e. Credit. Subject to the penalties assessed in *d* above, credit will be awarded as indicated in paragraph 18–6. Deductions will not exceed maximum allowable credit for test.

APPENDIX A
REFERENCES

A–1. Miscellaneous Publications

AR 117–5	Military Mapping and Geodesy.
AR 310–25	Dictionary of the United States Army Terms.
AR 310–50	Authorized Abbreviations and Brevity Codes.
AR 600–20	Army Command Policy and Procedures.
DA Pam 108–1	Index of Army Motion Pictures and Related Audio-Visual Aids.
DA Pam 310-series	Military Publications Indexes (as applicable).
FM 5–146	Engineer Topographic Units.
FM 6–10	Field Artillery Communications.
FM 6–20–1	Field Artillery Tactics.
FM 6–20–2	Field Artillery Techniques.
FM 6–40	Field Artillery Cannon Gunnery.
FM 6–120	Field Artillery Target Acquisition Battalion and Batteries.
FM 6–121	Field Artillery Target Acquisition.
FM 6–122	Artillery Sound Ranging and Flash Ranging.
FM 6–135	Adjustment of Artillery Fire by the Combat Soldier.
FM 6–140	Field Artillery Cannon Battalions and Batteries.
FM 21–5	Military Training Management.
FM 21–6	Techniques of Military Instruction.
FM 21–26	Map Reading.
FM 21–30	Military Symbols.
FM 21–31	Topographic Symbols.
FM 30–5	Combat Intelligence.
FM 44–1	U.S. Army Air Defense Artillery Employment.
FM 61–100	The Division.
TM 5–232	Elements of Surveying.
TM 5–236	Surveying Tables and Graphs.
TM 5–241–1	Grids and Grid References.
TM 5–241–2	Universal Transverse Mercator Grid, one-to-Zone Transformation Tables
TM 5–241–3/1	Universal Transverse Mercator Grid Tables for Latitudes 0°–80°; International Spheroid (Meters). Volume I, Transformation of Coordinates from Geographic to Grid.
TM 5–241–3/2	Universal Tranverse Mercator Grid Tables for Latitudes 0°–80°; International Spheroid (Meters). Volume II, Transformation of Coordinates from Grid to Geographic.
TM 5–241–4/1	Universal Transverse Mercator Grid Tables for Latitudes 0°–80°; Clarke 1866 Spheroid (Meters). Volume I, Transformation of Coordinates from Geographic to Grid.
TM 5–241–4/2	Universal Transverse Mercator Grid Tables for Latitude 0°–80°; Clarke 1866 Spheroid (Meters). Volume II, Transformation of Coordinates from Grid to Geographic.
TM 5–241–5/1	Universal Transverse Mercator Grid Tables for Latitudes 0°–80°; Bessel Spheroid (Meters). Volume I, Transformation of Coordinates from Geographic to Grid.

TM 5–241–5/2	Universal Transverse Mercator Grid Tables for Latitudes 0°–80°; Bessel Spheroid (Meters). Volume II, Transformation of Coordinates from to Geographic.
TM 5–241–6/1	Universal Transverse Mercator Grid Tables for Latitudes 0°–80°; Clarke 1880 Spheroid (Meters). Volume I, Transformation of Coordinates from Geographic Grid.
TM 5–241–6/2	Universal Transverse Mercator Grid Table for Latitudes 0°–80°; Clarke 1880 Spheroid (Meters). Volume II, Transformation of Coordinates from Grid to Geographic.
TM 5–241–7	Universal Transverse Mercator Grid Tables for 0°–45°; Everest Spheroid (Meters). Transformation of Coordinates from Geographic to Grid and from Grid to Geographic.
TM 5–241–8	Universal Transverse Mercator Grid.
TM 5–241–9	Universal Polar Stereographic Grid Tables for Latitudes 79° 30′–90°; International Spheroid (Meters). Transformation of Coordinates from Geographic to Grid and from Grid to Geographic.
TM 5–441	Topographic Surveying.
TM 5–6675–202–15	Operator, organizational, field and depot maintenance manual: Tellurometer, master unit: (Tellurometer (Pty) Ltd model MA1/CW/MV) FSN 6675–542–1415; tellurometer, remote unit (Tellurometer (Pty) Ltd model RA1/CW/MV) FSN 6675–542–1416.
TM 5–6675–203–15	Operator, Organizational Direct Support, General Support, and Depot Maintenance Manual, including repair parts and special tool lists: Altimeter, surveying, 4,500 meters, 2 meter divisions. (Wallace and Tiernan type FA–199) FSN 6675–641–3569.
TM 5–6675–207–15	Operator, Organizational, Direct Support, General Support and Depot Maintenance Manual: Surveying Instrument, Azimuth; Gyro; Artillery, w/gyroscope housing, electronic null indicator and mounting base (Autonetics models) (model ABLE C2A) FSN 6675–606–3378 (model ABLE C2B) FSN 6675–816–5624.
TM 5–6675–213–15	Operator, Organizational, Direct Support, General Support, and Depot Maintenance Manual, Theodolite, Directional, 1 Second Graduation. 5.9 in. length telescope w/tripod, carrying case and accessories (Wild Heerbrugg Instruments) model T–2, serial number ranges 5602 thru 17897 and 27235 thru 30594 FSN 6675–232–8972; model T–2–56, serial number range 50892 thru 55124 FSN 6675–587–3767 (TO 49A8–4–41).
TM 5–6675–232–15	Operator, organizational, DS, GS, and depot maintenance manual: Theodolite: Directional; 1 min. graduation; 5.9 in. long telescope w/accessories (Wild Heerbrugg model T–16, type I) FSN 6675–828–6397.
TM 5–6675–296–12	Operator, organizational Maintenance manual: Theodolite, directional; 0.002 mil graduation, 5.9 in. lg. telescope, detachable tribach, w/accessories and tripod (Wild Heerbrugg models) (model T2–56–C–MIL) FSN 6675–682–4635 (model T2–56–M–MIL) FSN 6675–796–9439, (model T2–63 MIL) FSN 6675–983–8027, (model T2–66–C–MIL) FSN 6675–937–2954 (model T2–68MIL) FSN 6675–089–8885, theodolite, directional (reference) (Wild Heerbrugg models T2–56–C–MIL, T2–56–M–MIL, T2–66–C–MIL, T2–67MIL, and T2–68MIL) FSN 6675–988–5225. Theodolites, directional/Wild Heerbrugg: T2–56–C–MIL; –M–MIL; –63MIL; –66–C–MIL; –68MIL. Theodolites, directional (ref)/Wild Heerbrugg: T2–56–C–MIL; –M–MIL; –63MIL; –66–C–MIL; –67MIL; –68MIL.
TM 5–6675–296–35	DS, GS, and depot maintenance manual; theodolite, directional; 0.002 mil graduation, 5.9 in. lg. telescope, detachable tribach, w/accessories and tripod (Wild Heerbrugg Models) (Model T2–56–C–MIL) FSN 6675–682–4635 (Model T2–56–M–MIL) FSN 6675–796–9439 (Model T2–63

	MIL) FSN 6675–983–8027 (Model T2–66–C–MIL) FSN 6675–937–2954 (Model T2–68MIL) FSN 6675–089–8885; theodolite, directional (Reference) (Wild Heerbrugg Models T2–56–C–MIL, T2–56–M–MIL, T2–63 MIL, T2–66–C–MIL, T2–67MIL, and T2–68MIL) FSN 6675–988–5225. Theodolites, directional/Wild Heerbrugg: T2–56–C–MIL, –M–MIL; –63MIL; –66–C–MIL; –68MIL. Theodolites, directional (reference)/ Wild Heerbrugg: T2–56–C–MIL; –M–MIL; –63MIL; –66–C–MIL; –67MIL; –68MIL.
TM 6–230	Logarithmic and Mathematical Tables.
TM 6–231	Seven Place Logarithmic Tables.
TM 6–240	Slide Rule, Military, Field Artillery.
TM 6–300–( )	Army Ephemeris, (appropriate year).
TM 9–1290–262–35	Field and Depot Maintenance Manual, Aiming Circle M2.
TM 9–6166	Operator and Organizational Maintenance; Aiming Circle M2.
Tellurometer Handbook	Tellurometer (PTY) Ltd, Cape Town, South Africa (issued with each unit).
Instructional Manual	EM 2171, for ABLE (Surveying) Instrument, Azimuth, Gyro Artillery, Model XC2A System w/Modified Electronic Package, Autonetics, North American Aviation, Inc.

A–2. DA Forms

5–72	Level, Transit, and General Survey Record.
5–139	Field Record and Computations-Tellurometer.
6–1	Computation-Azimuth and Distaance from Coordinates.
6–2	Computation-Coordinates and Height from Azimuth, Distance and Vertical Angle.
6–2b	Computation-Trigonometric Heights.
6–7a	Computation-Plane Triangle.
6–8	Computation-Plane Triangle Coordinates and Height from One Side, Three Angles and Vertical Angles.
6–10	Computation-Astronomic Azimuth by Hour-Angle Method, Sun.
6–10a	Computation-Astronomic Azimuth by Hour-Angle Method, Star.
6–11	Computation-Astronomic Azimuth by Altitude Method, Sun or Star.
6–18	Computation-Coordinates and Height from Two-Point Resection.
6–19	Computation-Coordinates and Height from Three-Point Resection.
6–20	Computation-Convergence (Astronomic Azimuth to UTM Grid Azimuth).
6–21	Computation and Instruction for Use with Star Identifier.
6–22	Computation-Conversion UTM Grid Coordinates to Geographic Coordinates(Machine).
6–23	Computation-Conversion Geographic Coordinates to UTM Grid Coordinates (Logarithmics).
6–25	Computation-Conversion Geographic Coordinates to UTM Grid Coordinates(Machine).
6–27	Computation-Altimetric Height (Single-Base or Leapfrog Method).
6–34	Zone to Zone UTM Grid Azimuth Transformation.
6–36	Zone to Zone UTM Grid Coordinates Transformation.
2972	Field Record and Computations-DME.
3613	Record—Survey Control Point.

A–3. Other U.S. Government Publications

The following publications are available from the Superintendent of Documents, US Government Printing Office, Washington, D.C.

a. Department of Commerce. Coast and Geodetic Survey: Special Publication No 225. Manual of Reconnaissance for Triangulation. Special

Publication No. 234, Signal Building. Special Publication No. 247, Manual of Geodetic Triangulation.

b. Department of the Navy. Naval Observatory: American Ephemeris and Nautical Almanac (published annually). Air Almanac (published annually). Hydrographic Office: H. O. No. 205, Radio Time Signals (current series).

A–4. Standardization Agreements

STANAG 2202 Map Conventional Signs.
STANAG 2210 Trig (Lists of Geodetic Data).
STANAG 2211 Geodetic Datums, Spheroids, Grids, and Grid References.

APPENDIX B

SURVEY SPECIFICATIONS

TRAVERSE*

Requirement	*Fourth-order*	*Fifth-order*
Adjusted	Yes	No
Closing error (position)		
Max Allowable Radial Error (position):	1:3,000	1:1,000
If traverse length is 9,000 M or more	1 M. $\sqrt{K}$	
If traverse length is less than 9,000 M	3,000 / Total distance (in meters)	
Not to exceed (Height)	$\sqrt{K}$	±2 meters
(Azimuth) Seven (7) or more MSA	0.1m $\sqrt{N}$	0.1 m × N
Six (6) or less MSA	0.04m × N	
Station between azimuth checks not to exceed	25	NA
Horizontal angles	1 D/R	1 position (1 D/R)
Vertical angles	1 D/R	1 D/R
Distance:		
Tape	Double tape to a comparative accuracy of 1:5,000	Single tape Check by pacing
Tellurometer (MRA-1)	2 coarse, 4 fine readings	2 coarse, 4 fine readings
DME (MC-8)	Measure in both directions	Measure in both directions
Scale factor	Yes	No
Horizontal and vertical angles recorded to	0.001 mil	0.1 mil
Azimuth carried to	0.001 mil	0.1 mil
Vertical angles and bearing angles used in computations to	0.01 mil	0.1 mil
Easting and northing coordinates computed to	0.01 meter	0.1 meter
Height computed to	0.1 meter	0.1 meter
Log tables used	7 place	6 place

**Note:* Always closed; on second known point as first choice, on starting point as second choice.

Legend:

K = length of traverse in kilometers.
N = number of main scheme angles in the traverse.
m = mil.
MSA = main scheme angles.

TRIANGULATION*

Requirement	*Fourth-order*	*Fifth-order*
Closing Error Not to Exceed: Position	1:3000	1:1000
Closing Error Not to Exceed: Length (Comparative Accuracy on Check Base)	1:3000	1:1000
Closing Error Not to Exceed: Height	$\sqrt{K}$	±2 meters
Closing Error Not to Exceed: Azimuth	0.04m × N	0.1m × N
Maximum Σ R_i	200	N/A
Between bases	Not to exceed 5 figures or when strength factor exceeds 200	
Azimuth check (Normally with base line check)	Not to exceed 5 figures or when strength factor exceeds 200	
Horizontal angles	2 positions (0.05m (10″) rejection limit between two positions	1 position
Vertical angles	1–D/R	1–D/R
Base Determination:		
Known coordinates	see para 10–6*c*(1)	see para 10–6*c*(1)
Tape	Double-tape to comp. accuracy of 1:7000	Double-tape to comp. accuracy of 1:3000
Tellurometer (MRA 1)	2 coarse, 4 fine readings	2 coarse, 4 fine readings
DME (MC8)	Measure in both directions	Measure in both directions
Horizontal and vertical angles recorded to	0.001 mil	0.1 mil
Azimuth carried to	0.001 mil	0.1 mil
Vertical angles and bearing angles used in computations to	0.01 mil	0.1 mil
Easting and Northing coordinates computed to	0.01 meter	0.1 meter
Height computed to	0.1 meter	0.1 meter
Log tables used	7-place	6-place
Scale factor	Yes	No
Minimum distance angles	400 mils	400 mils
Triangle closure	Avg for scheme 0.05 mil per triangle; max per triangle 0.06 mil	0.3 mil

*Closed on known control if possible; if not, through use of length checks (para 10–8c).

Legend:

K = length in kilometers.
N = number of stations for carrying azimuth.
m = mil.

TRILATERATION*

Requirement	*Fourth-order*
Desirable	Quadrilateral (Single chain permissible in a limited time survey only).
Desirable Minimum side length	5,000 meters
Minimum permissible angle	400 mils (Preferably 533m).
Height (by altimetry)	Corrected scale reading computed to 0.1 meter. End results +3-5 meters (average error)
Azimuth	Established at terminal point by astro or gyro. (0.15m considered accuracy).
Between bases	Not to exceed 3 quadrilaterals or 30,000 M, whichever comes first.
Distances	Measured in both directions; comparative accuracy 1:25,000.
Angle check (Quads only)	At each corner the sum of two small angles will be compared with the large angle. The two must agree, within ±0.2m.
Azimuth carried	To 0.01 mil through angles which most nearly equal 1,000 mils.
Position carried	To 0.01 meter through lines used for azimuth. Use angles from DA Form 6–7a and DA Form 6–2.

ASTRONOMIC OBSERVATIONS

Requirement	Fourth-order (1:3,000)	Fifth-order (1:1,000)	(1:500*)
Minimum number of sets to be observed	3	3	4 mil
Rejection limit	0.15 mil	0.3 mil	0.3 mil
Number of sets that must remain and be remeaned	2	2	3
Horizontal angles	1 position	1 position	2 reading
Vertical angles	1 D/R	1 D/R	2 readings
Considered accuracy	0.15 mil	0.3 mil	0.3 mil

*Specifications apply for determining a fifth-order azimuth. If the direction is not extended from the line established by the observation, the rejection limit can be relaxed to 1.0 mil with a considered accuracy 1.0 mil.

APPENDIX C
DUTIES OF SURVEY PERSONNEL

C-1. Survey Officer

The survey officer—

a. Coordinates and supervises the training of survey personnel.

b. Coordinates, supervises, and emphasizes the preventive maintenance program on survey equipment.

c. Coordinates, supervises, and establishes the survey information center (when the ISC is authorized at his echelon).

d. Accompanies the commander on reconnaissance.

e. Formulates and implements the survey plans.

f. Supervises and coordinates the field operation of survey parties under his jurisdiction.

g. Advises the commander and staff on survey matters.

h. Coordinates survey operations with survey officers of higher, lower, and adjacent headquarters.

C-2. Chief Surveyor

The chief surveyor—

a. Acts as the principal assistant to the survey officer and when directed performs any or all of the duties of the survey officer.

b. Supervises survey personnel in performance of routine reconnaissance, communications, and survey activities.

c. Performs other duties as directed.

C-3. Chief of Survey Party

The chief of survey party—

a. Trains his survey party.

b. Implements his party's portion of the survey plan.

c. Orients party members of the survey plan.

d. Supervises and coordinates the field operation of his survey party.

e. Maintains liaison with the survey officer or chief surveyor during field operations.

f. Supervises preventive maintenance on section equipment, to include vehicles and communications equipment.

g. Performs other duties as directed.

C-4. Survey Computer

The survey computer—

a. Maintains the required DA Forms for computation of surveys.

b. Performs independent computations during field operations.

c. Performs other duties as directed.

C-5. Instrument Operator

The instrument operator—

a. Performs preventive maintenance on the authorized instruments.

b. Operates the instruments during field operations.

c. Verifies the vertical alinement of the range pole before measuring angles during field operations.

d. Reads the measured values to the recorder and checks the recorder's operation by use of a read-back technique.

e. Familiarizes himself with the fieldwork requirements for all survey methods.

f. Assists the tapemen in maintaining alinement during taping operations.

g. Performs other duties as directed.

C-6. Recorder

The recorder—

a. Maintains an approved notebook (DA Form 5-72, Level, Transit, and General Survey Record) or field book record of all surveys performed by the survey party.

b. Records survey starting data and all measured data with a hard-lead pencil in a neat and legible manner during field operations.

c. Sketches, in the approved notebook, complete schematic sketches and describes concisely and completely the principal stations occupied during field survey operations.

d. Checks, means, and adjusts angular data measured by the instrument operator.

e. Checks taped distances by pacing (Fifth-order and 1:500 surveys only).

f. Provides required field data to the survey computers independently.

g. Performs other duties as directed.

h. Computes sea-level distances when electronic measuring devices are used.

C-7. Tapeman

The tapeman—

a. Maintains the fourth-order field artillery fire control surveying set.

b. Tapes distances, using proper taping techniques, during field operations.

c. Computes an accuracy ratio for taped distance when required.

d. Reports measured distances to the recorder.

e. Operates and maintains the section radio equipment.

f. Performs other duties as directed.

Note. The rear tapeman commands the taping team.

APPENDIX D
GLOSSARY

Section I. PRACTICAL ASTRONOMY TERMS

The following glossary of terms is provided primarily for information and reference. Though all terms defined have not been mentioned in this text, they, are, generally, terms which the field artillery surveyor will encounter in the field.

Altitude—The altitude of a celestial body is the arc of its vertical circle measured from the horizon to the body, or it is the vertical angle at the observer's position between the horizon and the body.

Angle t—Angle *t* is the interior angle of the PZS triangle at the pole. It is measured either eastward or westward between the observer's meridian and the hour circle of the celestial body.

Azimuth—The angular distance measured along the horizon in a clockwise direction from the meridian to the vertical circle through the body.

Azimuth Angle—The angle less than 180° between the plane of the celestial meridian and the vertical plane containing the observed object, reckoned from the direction of the elevated pole. In astronomic work, the azimuth angle is the spherical angle at the zenith in the astronomical triangle which is composed of the pole, the zenith, and the star.

Celestial coordinates—The coordinates used to locate a heavenly body by various systems. The coordinates used in the artillery are declination and right ascension.

Celestial equator—The great circle on the celestial sphere formed by the plane of the earth's equator when it is extended. A *great circle* is a circle, the plane of which passes through the center of a sphere.

Celestial poles, North and South—The points at which the prolonged polar axis of the earth intersects the celestial sphere.

Celestial sphere—An imaginary sphere of infinite radius whose center is the center of the earth. (In practical astronomy, it is assumed that the earth is stationary and that the celestial bodies rotate about the earth from east to west on this sphere).

Coaltitude—The side of the PZS triangle from the celestial body to the zenith.

Colatitude—The side of the PZS triangle from the celestial pole to the zenith.

Culimation—The passage of the celestial body across the meridian of the observer. Every celestial body will have two culimations; the passage across the upper arc of the meridian is *upper culimination* or *upper transit*, and the passage across the lower arc is *lower culimination*, or *lower transit*.

Declination—The angular distance from the celestial equator measured along the hour circle of the body. Declination is given a positive sign when the body is north of the celestial equator and negative, when south. Declination corresponds to latitude on the earth.

Ecliptic—The great circle formed on the celestial sphere by the plane of the earth's orbit. If one could observe the sun and the stars at the same time, he would see the sun and stars moving slowly across the sky, with the sun gaining slightly on the stars each day. Therefore, since for practical astronomy's purposes, the earth is assumed to be stationary, the ecliptic is assumed to be the path of the sun. This ecliptic intersects the celestial equator at two points at an angle of 23½°.

Elongation—The elongations of a celestial body are two points in its apparent orbit at which the bearing from the observer's meridian is the greatest. A star is said to be at *eastern elongation* when its bearing is a maximum to the east and at *western elongation* when its bearing is a maximum to the west.

Equinox—The equinoxes are the two points where the ecliptic intersects the celestial equator. The point where the sun crosses the celestial equator from south to north is called the *vernal equinox* or first point of Aries. The other point is called the *autumnal equinox* and is diametrically opposite the first point. The equinoctial points move slowly westward along the ecliptic rate of about 50 seconds a year. As a result, all the fixed stars gradually change their positions with respect to the equator and the vernal equinox

Horizon—The horizon for any place on the earth's surface is the great circle formed on the celestial sphere by the extension of the plane of the observer's horizon.

Hour Angle—The angle at the celestial poles between the plane of the meridian of the observer and the plane of the hour circle of the star. Stated simply, the hour angle is the angle at the pole between the observer's meridian and the meridian (hour circle) of the celestial body. This angle is similar to differences in longitude on the earth's surface. It is measured westward from the observer's meridian. The hour angle is generally considered as an arc measured along the celestial equator toward the west and may be expressed in time or arc.

Hour Circle—Any great circle on the celestial sphere that passes through the celestial poles.

Latitude—The angular distance, for a specific spot on the eath's surface, from 0° to 90° north or south of the equator.

Longitude—The angular distance, for a specific spot on the earth's surface, from 0° to 180° east or west of the meridian of Greenwich, which is used by most nations as the prime or initial meridian.

Observer's Meridian—The great circle on the celestial sphere which passes through the celestial poles and the observer's zenith.

Parallax—The difference in altitude of a body as seen from the center of the earth and from a point on the surface of the earth. There is no apparent parallax of the fixed stars, but that of the sun and planets is measurable. Parallax makes the body appear lower than it actually is; therefore, the correction is added.

Polar Distance—The algebraic complement of the declination. (90° minus the declination.)

Prime Vertical—The prime vertical for any place on the earth's surface is the vertical circle perpendicular to the meridian. It intersects the horizon at the points directly east or west.

Refraction—The refraction of a celestial body is the apparent displacement of the body caused by the bending of light rays passing through layers of air of varying density. The celestial body will appear higher than it really is; therefore, the correction is subtracted. A simple example of refraction can be noted by placing a spoon in a glass half full of water.

Revolution—The earth revolves about the sun on a 600-million-mile orbit at a speed of about 18.5 miles per second. In practical astronomy, it is assumed that the earth is stationary and that the celestial bodies move about it from east to west on the celestial sphere.

Right Ascension—The right ascension of a celestial body is the arc on the celestial equator measured from the vernal equinox eastward to the hour circle of the body. It is measured in units of time from 0 to 24 hours. Right ascension corresponds to longitude on earth.

Rotation—The turning of a body on its axis. The terminal points of the axis of the earth are the north and south poles. The rotation is from west to east.

Solstices—The solstices are two points on the ecliptic midway between the equinoxes. When the ecliptic is north of the celestial equators, the midpoint is called the *summer solstice* and occurs about 21 June; when the ecliptic is south of the celestial equator, the midpoint is called the *winter solstice* and occurs about 21 December. It is easily seen, then, that the solstices occur when the sun is at its greatest distance north or south of the equator.

Vertical Circle—Any great circle on the celestial sphere which passes through the zenith.

Zenith and Nadir—The zenith and nadir for any place on the earth's surface are the two points where an extension of the observer's plumb line intersects the celestial sphere. The zenith is the point directly overhead and the nadir is the point directly underneath.

Section II. GENERAL SURVEY TERMS

Accuracy—The degree of conformity with a standard.

Azimuth—The horizontal angle measured clockwise between a reference direction and the line to an observed or designated point.

Azimuth, astronomic—At the point of observation, an astronomic azimuth is the angle between a vertical plane through the celestial pole and the vertical plane through the observed object.

Azimuth, geodetic—At the point of observation, an angle between a tangent to the meridian and the tangent to a geodetic line passing through the observed object. (See survey, geodetic.)

Azimuth, grid—An azimuth measured from grid north. (See azimuth, plane, and azimuth, projected geodetic.)

Azimuth, magnetic—An azimuth measured from magnetic north.

Azimuth, plane—The angle measured in a clockwise direction between grid north and a line on the grid.

Azimuth, projected geodetic—At the point of observation, the horizontal angle measured clockwise between grid north and the tangent to the geodetic line to an observed or designated point. This term *must not* be confused with geodetic azimuth.

Base line—A surveyed line established with more than usual care, used as a known length of a triangle side, for computing other triangle sides. When misinterpretation is not probable the abbreviated term "base" may be used.

Basic control—Horizontal or vertical control, in which the locations of the stations have been accurately coordinated and correlated, forming a framework to which other surveys are adjusted. For artillery purposes, this term can be applied to control points established by fourth or higher orders of accuracy.

Datum—A reference element, such as a line or plane, in reference to which the positions of other elements are determined. (See horizontal datum and level datum.)

Datum, horizontal—In plane surveying, the grid system of reference used for the horizontal control of an area; defined by the easting and northing of one station in the area and the azimuth from this selected station to an adjacent station. This is differentiated from the term "common grid" in that the latter implies a common datum.

Datum, level—A level surface to which heights are referred. The generally adapted level datum is mean sea level. For tactical surveys, an arbitrary level datum is often assumed as in the case of some local surveys in which arbitrary level datums are often adopted and defined in terms of an assumed elevation for some physical mark (bench mark).

Distance, horizontal—The distance measured in a horizontal plane, as distinguished from a distance measured on a slope. Horizontal distance refers primarily to taped distances or to distances reduced to horizontal by computations.

Electronic line of sight—The characteristics of intervening terrain which make possible the transmission of a radio wave between two separated components of the electronic distance measuring equipment systems.

Fairchild MC-8 system (DME system)—A system for electronic distance measurement. A complete system consists of three identical instruments with other associated items which contribute to the physical operation of these instruments or the correction of data obtained from them. Two units are needed to perform the measurements with either unit serving as a measurer or a responder by means of a selector switch. The DME system is to replace the Tellurometer.

One-position, two-position—Refers to initial readings on the circle of the instrument measuring an angle and is used to determine the degree of refinement in the performance of angular value determinations with the theodolite.

Registration point—A point in the target area, the location of which is known on the ground and on the firing chart, and on which a precision registration is conducted to obtain firing data corrections.

Rejection limit—When used in field artillery survey, refers to a maximum allowable deviation from a mean value of two or more angular measurements.

Restitution point—A point identifiable on a photograph whose chart location is known and which is used to transfer (restitute) other points from the photograph to the firing chart. The chart location of these points may be determined by inspection or by survey.

Set (one set, two sets, etc.)—Used in reference to astronomic observations of a celestial body. One set consists of the field data that result from the observation of a celestial body with the telescope of the observing instrument, first in the direct position then in the reverse position.

Slope distance—The straight line distance between two points of unequal height. Normal usage is associated with electronic distance measuring equipment. *(Do not use slant distance.)*

Survey, geodetic—That survey which takes into consideration the size and shape of the earth; implies a reference spheroid which represents the geoid and the horizontal and vertical control datums.

Survey, plane—That survey in which the effect of the curvature of the earth is almost entirely neglected and computations of the relative positions of the stations are made, using the principles of plane geometry and plane trigonometry.

Tellurometer master station—That survey station over which the tellurometer master instrument is placed for operations.

Tellurometer remote station—The survey station over which the tellurometer remote instrument is placed for operation.

Tellurometer system (MRA-1)—A system for electronic distance measurement. A complete system consists principally of one master instrument and two remote instruments with other associated items which contribute to the physical operation of these instruments or the correction of data obtained from them.

APPENDIX E
STAR RATE INDEX

TO USE THE PLATES:

1. Place the star identifier corresponding to the observer's latitude over the plate in the appendix.

2. Trace the curve for the rate desired, using a sharp grease pencil.

3. The areas are marked on the plates as follows:

   a. *Area A.* The rate if between 0 and 0.5. The dotted line indicates a rate of zero. Stars within this area are the most desirable for use in observations. Stars at higher altitudes are more difficult to use.

   b. *Area B.* The rate is between 0.5 and 1.0. Stars within this area are the second most desirable. Fourth-order azimuth can be obtained from these stars using reasonable care.

   c. *Area C.* The rate is between 1.0 and 3.0. Stars within this area are the third most desirable. Fifth-order azimuth can be obtained from these stars using reasonable care.

   d. *Area D.* The rate is over 3.0. Stars within this area should not be used; however, if they are used, the azimuth must be determined by the hour-angle method.

4. The area above 60 altitude is blank, because stars in this area should not be used.

5. Select stars that are within the area best suited for the accuracy desired and will meet the tactical situation.

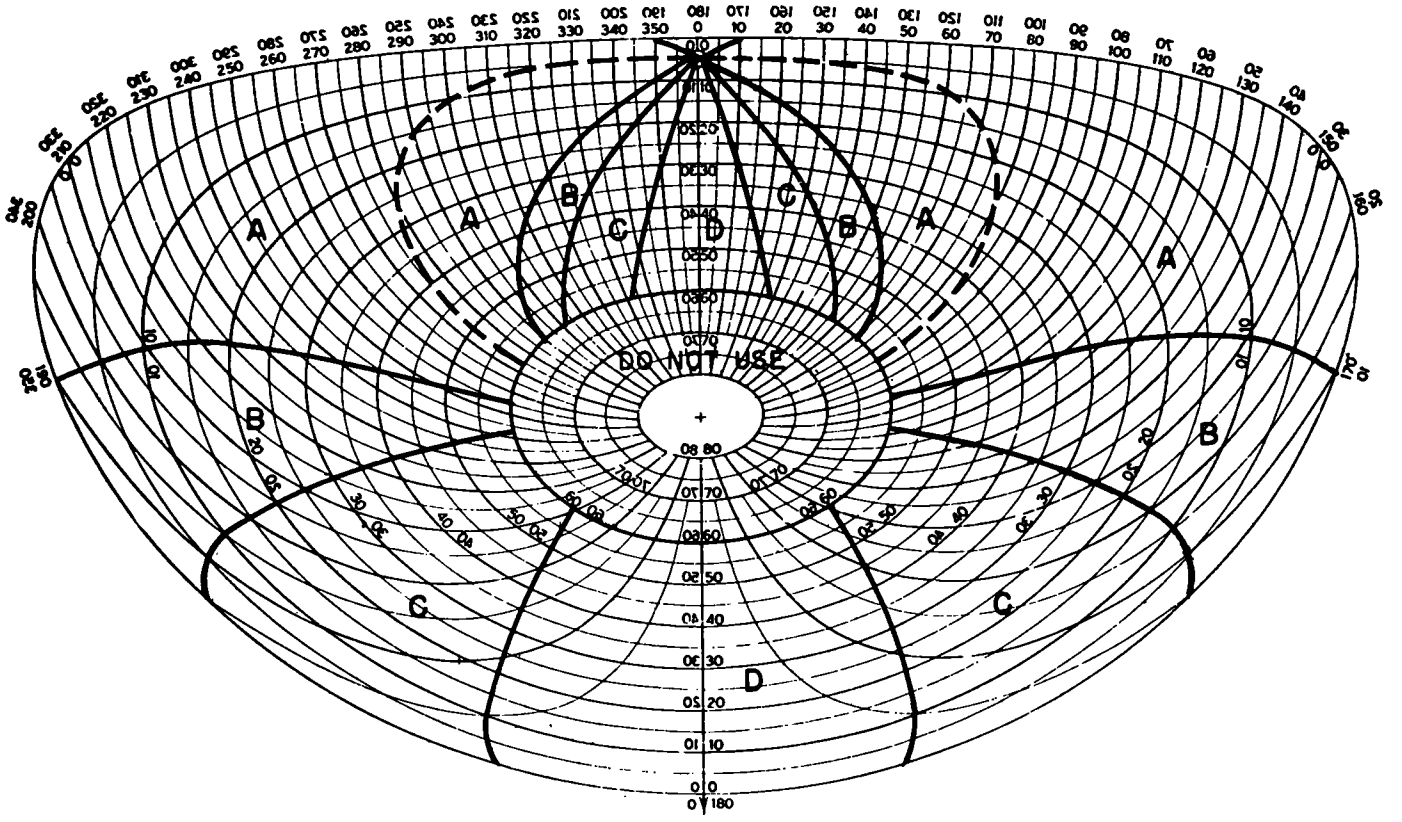


Plate 1.

LATITUDE 15°S

LATITUDE 15°N

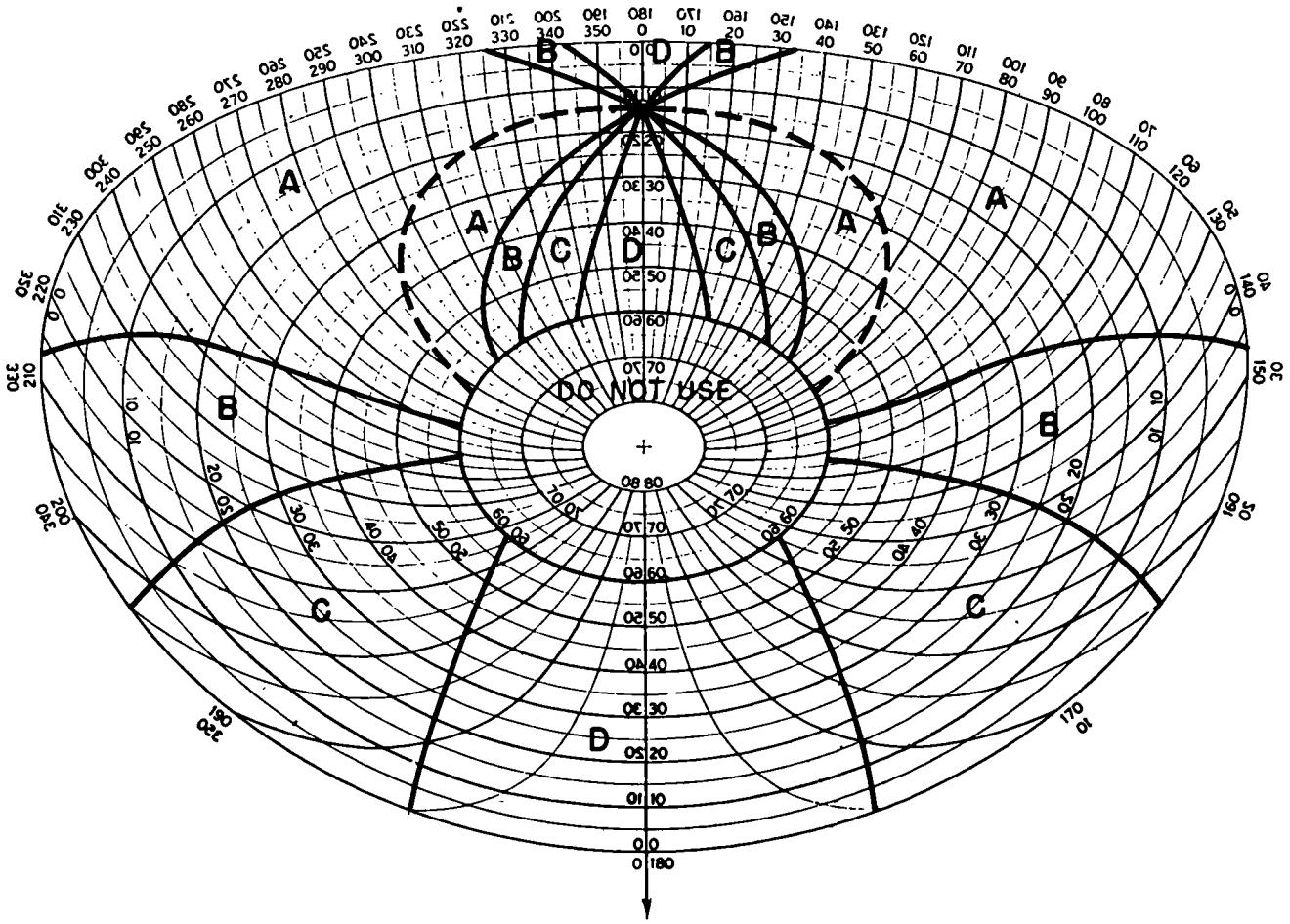


Plate 2.

LATITUDE 25°N

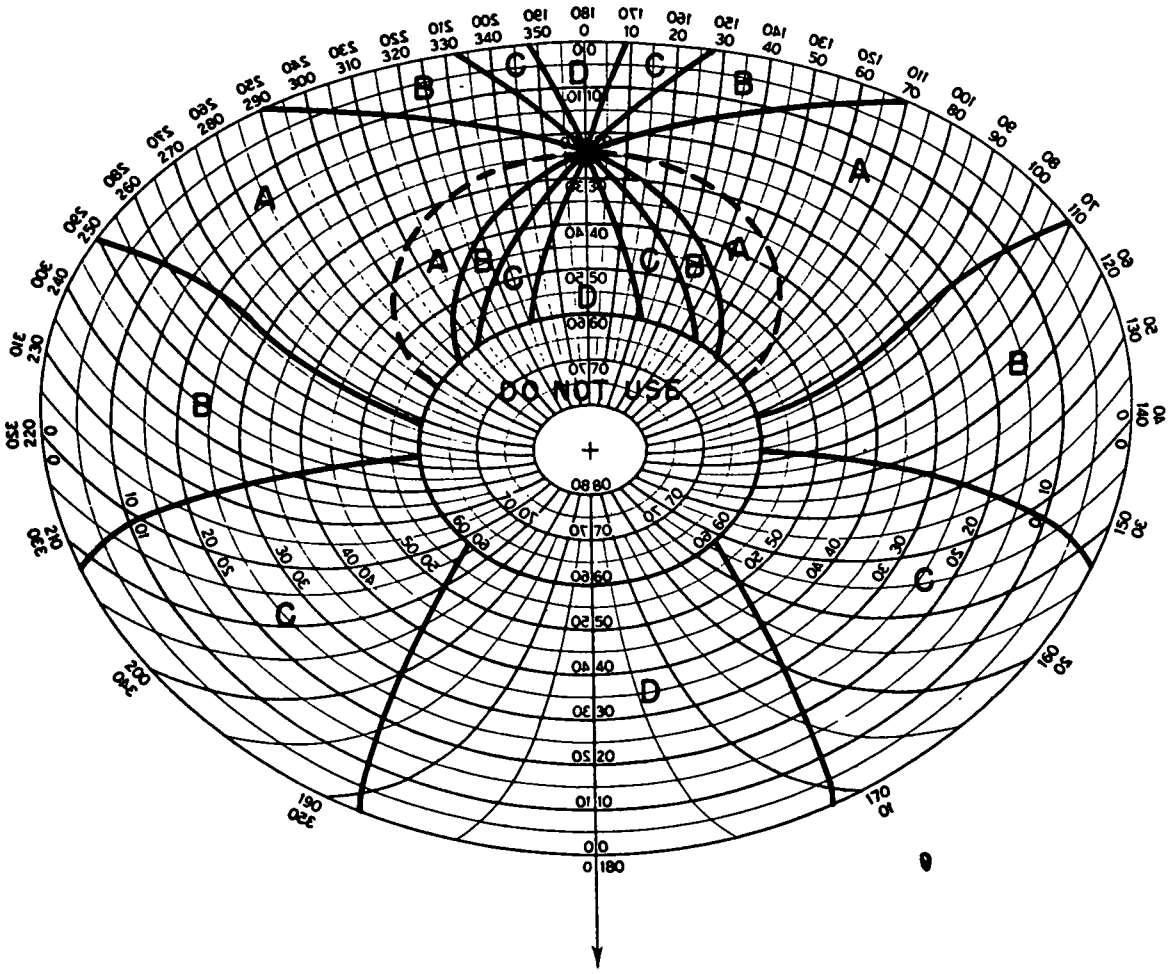


Plate 3.

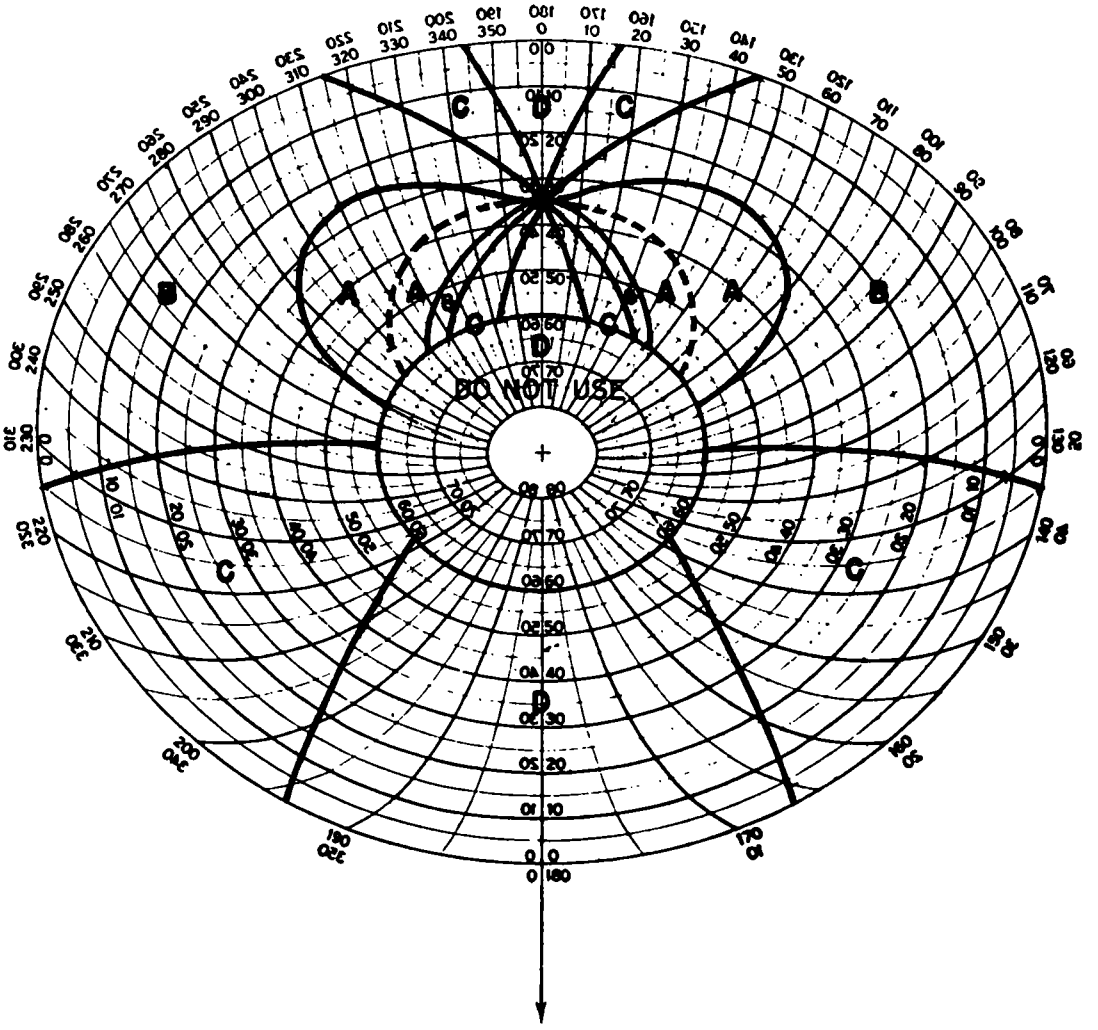


Plate 4.

LATITUDE 45'N

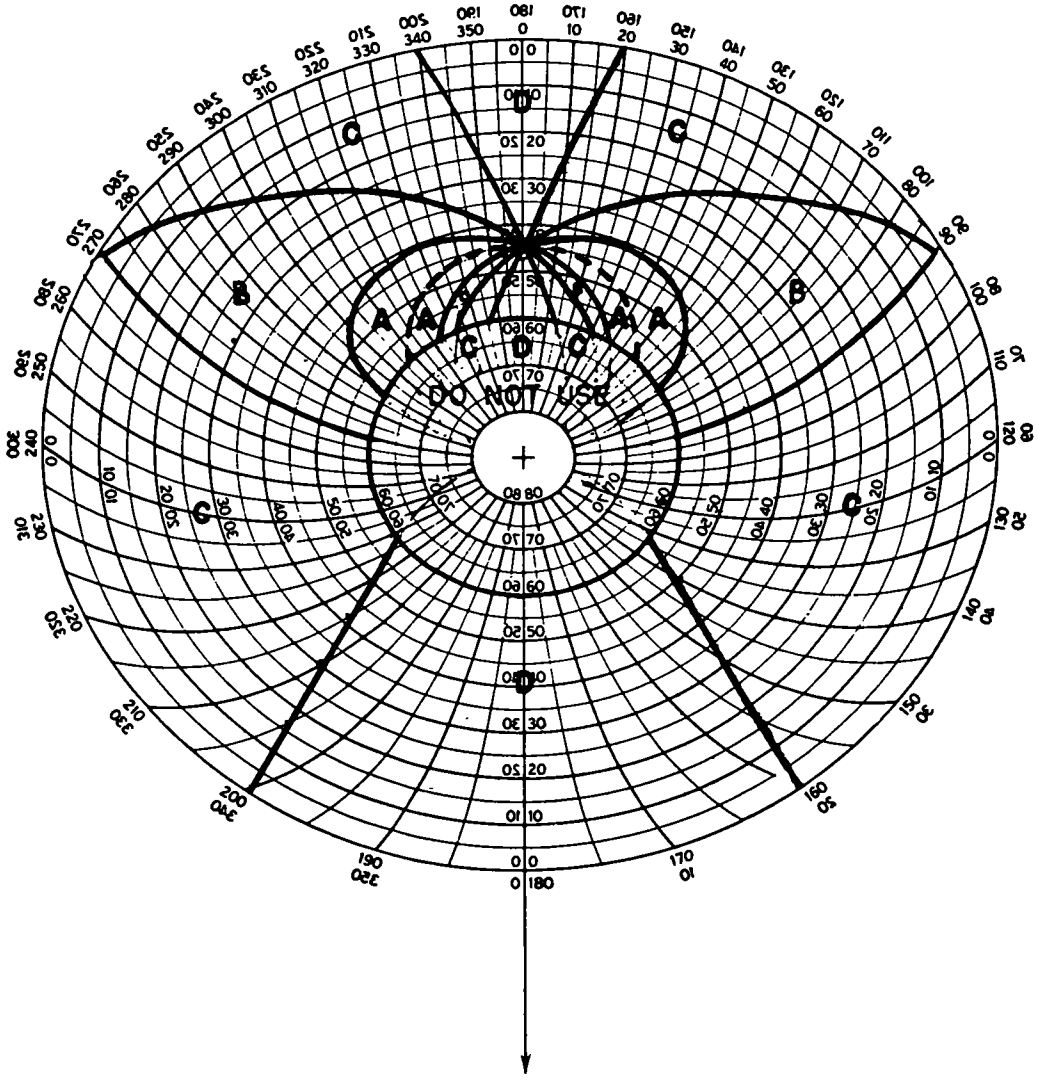


Plate 5.

LATITUDE 55°N

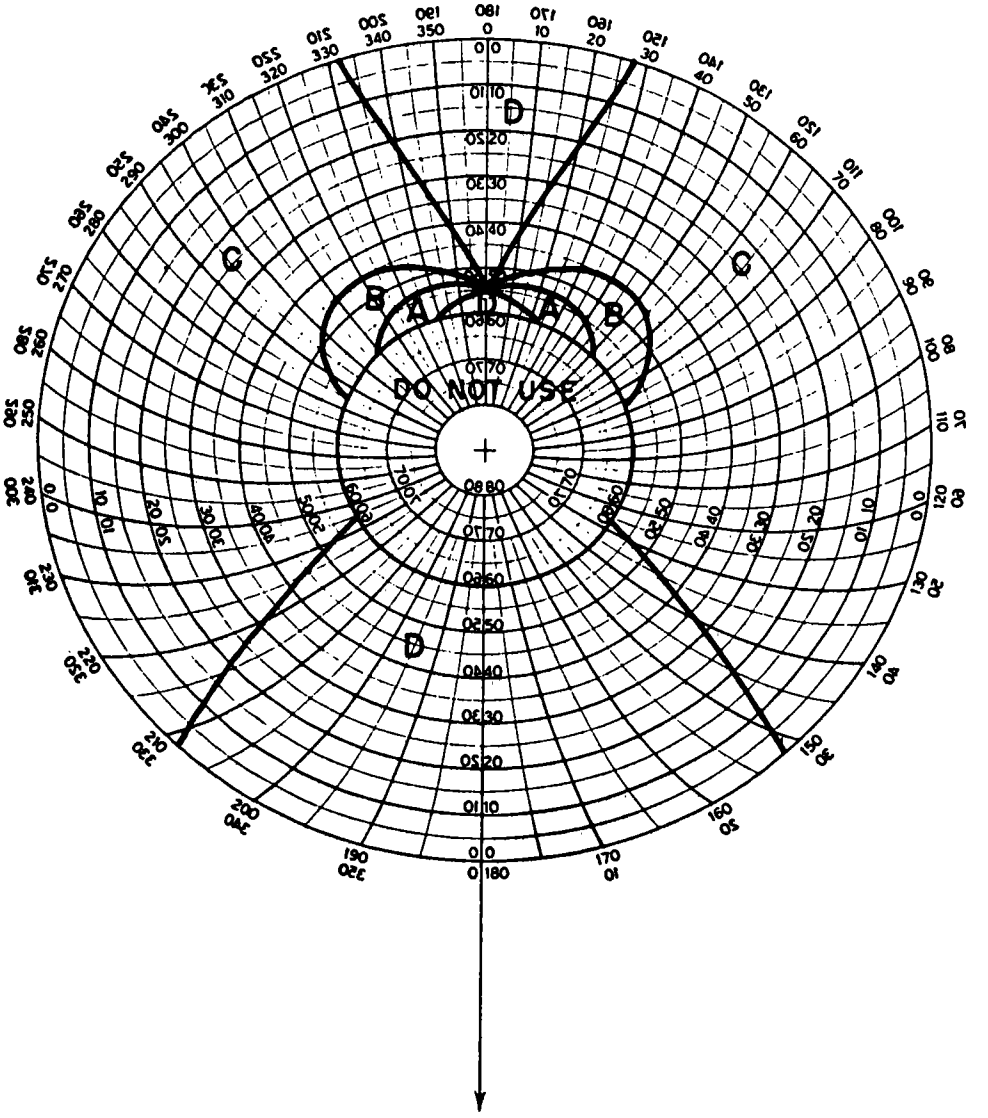


Plate 6.

LATITUDE 65N

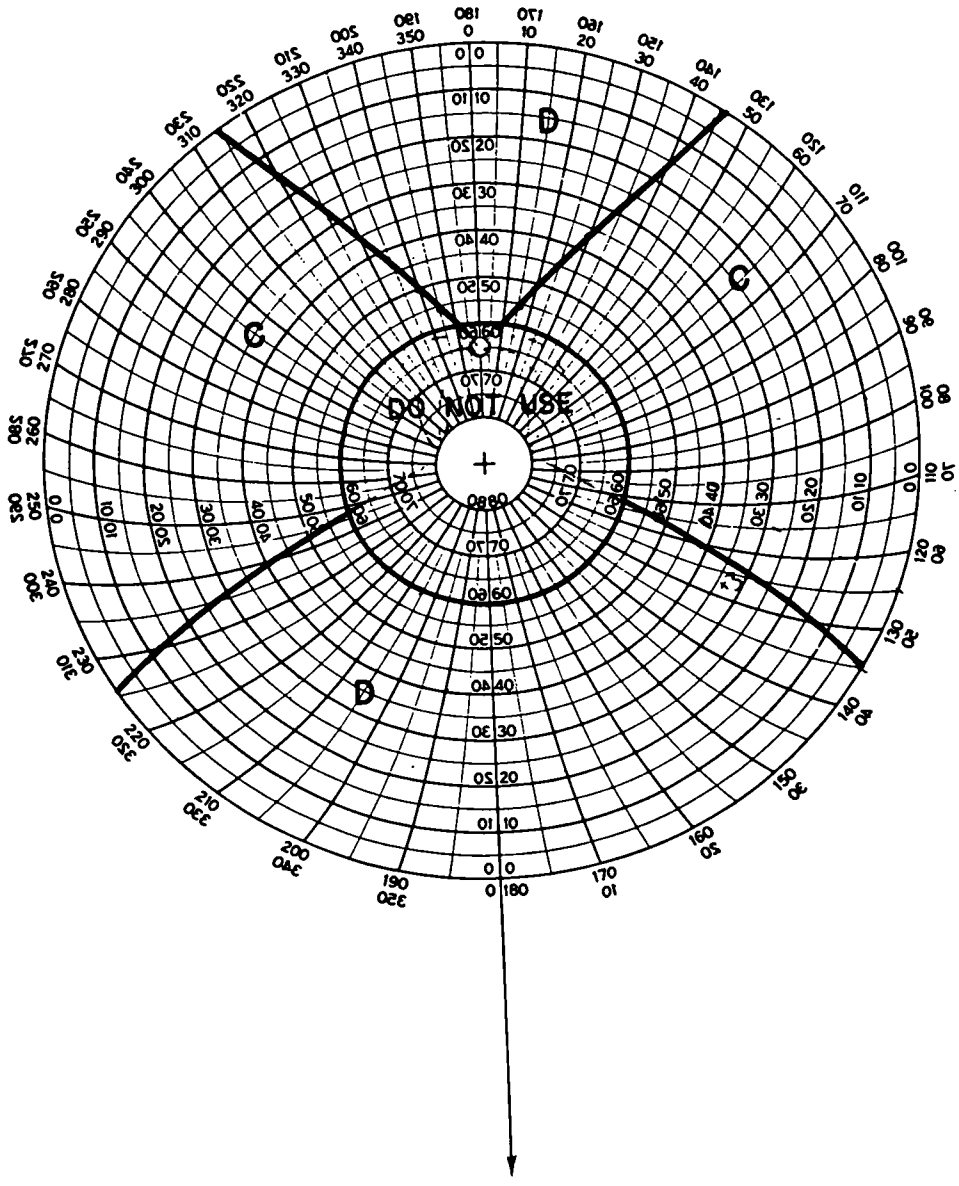


Plate 7.

APPENDIX F

CONVERSION OF ARC TO TIME

DEGREES						MINUTES		SECONDS					
°	h m	°	h m	°	h m	′	m s	″	s	″	s	″	s
0	0 00	60	4 00	120	8 00	0	0 00	0	0.000	0.00	0.000	0.50	0.033
1	0 04	61	4 04	121	8 04	1	0 04	1	0.067	.01	.001	.51	.034
2	0 08	62	4 08	122	8 08	2	0 08	2	0.133	.02	.001	.52	.035
3	0 12	63	4 12	123	8 12	3	0 12	3	0.200	.03	.002	.53	.035
4	0 16	64	4 16	124	8 16	4	0 16	4	0.267	.04	.003	.54	.036
5	0 20	65	4 20	125	8 20	5	0 20	5	0.333	0.05	0.003	0.55	0.037
6	0 24	66	4 24	126	8 24	6	0 24	6	0.400	.06	.004	.56	.037
7	0 28	67	4 28	127	8 28	7	0 28	7	0.467	.07	.005	.57	.038
8	0 32	68	4 32	128	8 32	8	0 32	8	0.533	.08	.005	.58	.039
9	0 36	69	4 36	129	8 36	9	0 36	9	0.600	.09	.006	.59	.039
10	0 40	70	4 40	130	8 40	10	0 40	10	0.667	0.10	0.007	0.60	0.040
11	0 44	71	4 44	131	8 44	11	0 44	11	0.733	.11	.007	.61	.041
12	0 48	72	4 48	132	8 48	12	0 48	12	0.800	.12	.008	.62	.041
13	0 52	73	4 52	133	8 52	13	0 52	13	0.867	.13	.009	.63	.042
14	0 56	74	4 56	134	8 56	14	0 56	14	0.933	.14	.009	.64	.043
15	1 00	75	5 00	135	9 00	15	1 00	15	1.000	0.15	0.010	0.65	0.043
16	1 04	76	5 04	136	9 04	16	1 04	16	1.067	.16	.011	.66	.044
17	1 08	77	5 08	137	9 08	17	1 08	17	1.133	.17	.011	.67	.045
18	1 12	78	5 12	138	9 12	18	1 12	18	1.200	.18	.012	.68	.045
19	1 16	79	5 16	139	9 16	19	1 16	19	1.267	.19	.013	.69	.046
20	1 20	80	5 20	140	9 20	20	1 20	20	1.333	0.20	0.013	0.70	0.047
21	1 24	81	5 24	141	9 24	21	1 24	21	1.400	.21	.014	.71	.047
22	1 28	82	5 28	142	9 28	22	1 28	22	1.467	.22	.015	.72	.048
23	1 32	83	5 32	143	9 32	23	1 32	23	1.533	.23	.015	.73	.049
24	1 36	84	5 36	144	9 36	24	1 36	24	1.600	.24	.016	.74	.049
25	1 40	85	5 40	145	9 40	25	1 40	25	1.667	0.25	0.017	0.75	0.050
26	1 44	86	5 44	146	9 44	26	1 44	26	1.733	.26	.017	.76	.051
27	1 48	87	5 48	147	9 48	27	1 48	27	1.800	.27	.018	.77	.051
28	1 52	88	5 52	148	9 52	28	1 52	28	1.867	.28	.019	.78	.052
29	1 56	89	5 56	149	9 56	29	1 56	29	1.933	.29	.019	.79	.053
30	2 00	90	6 00	150	10 00	30	2 00	30	2.000	0.30	0.020	0.80	0.053
31	2 04	91	6 04	151	10 04	31	2 04	31	2.067	.31	.021	.81	.054
32	2 08	92	6 08	152	10 08	32	2 08	32	2.133	.32	.021	.82	.055
33	2 12	93	6 12	153	10 12	33	2 12	33	2.200	.33	.022	.83	.055
34	2 16	94	6 16	154	10 16	34	2 16	34	2.267	.34	.023	.84	.056
35	2 20	95	6 20	155	10 20	35	2 20	35	2 333	0.35	0.023	0.85	0.057
36	2 24	96	6 24	156	10 24	36	2 24	36	2.400	.36	.024	.86	.057
37	2 28	97	6 28	157	10 28	37	2 28	37	2.467	.37	.025	.87	.058
38	2 32	98	6 32	158	10 32	38	2 32	38	2.533	.38	.025	.88	.059
39	2 36	99	6 36	159	10 36	39	2 36	39	2.600	.39	.026	.89	.059
40	2 40	100	6 40	160	10 40	40	2 40	40	2.667	0.40	0.027	0.90	0.060
41	2 44	101	6 44	161	10 44	41	2 44	41	2.733	.41	.027	.91	.061
42	2 48	102	6 48	162	10 48	42	2 48	42	2.800	.42	.028	.92	.061
43	2 52	103	6 52	163	10 52	43	2 52	43	2.867	.43	.029	.93	.062
44	2 56	104	6 56	164	10 56	44	2 56	44	2.933	.44	.029	.94	.063
45	3 00	105	7 00	165	11 00	45	3 00	45	3.000	0.45	0.030	0.95	0.063
46	3 04	106	7 04	166	11 04	46	3 04	46	3.067	.46	.031	.96	.064
47	3 08	107	7 08	167	11 08	47	3 08	47	3.133	.47	.031	.97	.065
48	3 12	108	7 12	168	11 12	48	3 12	48	3.200	.48	.032	.98	.065
49	3 16	109	7 16	169	11 16	49	3 16	49	3.267	.49	.033	0.99	.066
50	3 20	110	7 20	170	11 20	50	3 20	50	3.333	0.50	0.033	1.00	0.067
51	3 24	111	7 24	171	11 24	51	3 24	51	3.400				
52	3 28	112	7 28	172	11 28	52	3 28	52	3.467				
53	3 32	113	7 32	173	11 32	53	3 32	53	3.533				
54	3 36	114	7 36	174	11 36	54	3 36	54	3.600				
55	3 40	115	7 40	175	11 40	55	3 40	55	3.667				
56	3 44	116	7 44	176	11 44	56	3 44	56	3.733				
57	3 48	117	7 48	177	11 48	57	3 48	57	3.800				
58	3 52	118	7 52	178	11 52	58	3 52	58	3.867				
59	3 56	119	7 56	179	11 56	59	3 56	59	3.933				

90° = 6h

180° = 12h

270° = 18h

which, from its point of origin at a second order astronomic azimuth line or higher order direction, has depreciated in accuracy by a probable error value of 3.0 seconds (0.02 mil) per main scheme angle, or the azimuth of a line determined by computation between a second order survey control point and a survey control point of equal or higher order. In the latter case, considered accuracy (90 percent + assurance) for use by field artillery survey is 7 seconds (0.03 mil).

Third Order Survey — Survey performed to an accuracy of a maximum closing error of 1 unit of error in 5,000 similar units of survey using third order procedures. Usually written 1:5,000 (not a field artillery accuracy).

Third Order Astronomic Azimuth — An azimuth established by third order astronomical methods, the probable error of the result of which does not exceed 5.0 seconds (0.02 mil). Considered accuracy (90 percent + assurance) for field artillery survey is 12.5 seconds (0.06 mil).

Third Order Azimuth — An azimuth of a line used in the extension from its point of origin at a third order astronomic azimuth line or higher order direction, has depreciated in accuracy by a probable error value of 6.0 seconds (0.03) mil per main scheme angle, or the azimuth of a line determined by computation between a third order survey control point and a survey control point of equal or higher order. In the latter case, considered accuracy (90 percent + assurance) for field artillery survey is 36 seconds (0.18 mil).

Fourth Order Survey — Field Artillery Survey performed to an accuracy of 1 unit of error in 3,000 similar units of survey. Usually written 1:3,000.

Fourth Order Astronomic Azimuth — A field artillery azimuth established by astronomical methods, the probable error of the result of which does not exceed 12.0 seconds (0.06 mil). Considered accuracy (90 percent + assurance) for field artillery survey is 30 seconds (0.15 mil).

APPENDIX H

ORDERS OF SURVEY ACCURACIES

First Order Survey	Survey performed to an accuracy of a maximum closing error of 1 unit in 25,000 similar units of survey using first order procedures. Usually written 1:25,000 (not a field artillery accuracy).
First Order Astronomic Azimuth	An azimuth established by first order astronomical methods, the probable error of the results of which does not exceed 0.5 second (0.0 mil). Considered accuracy (90 percent + assurance) for use by field artillery survey is 1.5 seconds (0.01 mil).
First Order Azimuth	An azimuth of a line used in the extension of 1st order survey which, if originated from a first order astronomic azimuth line, has depreciated in accuracy by a probable error value of 1.5 seconds (0.01 mil), per main scheme angle, or the azimuth of a line determined by computation between two first order survey control points. In the latter case, considered accuracy (90 percent + assurance) for use by artillery survey is 3 seconds (0.01 mil).
Second Order Survey	Survey performed to an accuracy of a maximum closing error of 1 unit in 10,000 similar units of survey using second order procedures. Usually written 1:10,000 (not a field artillery accuracy).
Second Order Astronomic Azimuth	An azimuth established by second order astronomical methods, the probable error of the results of which does not exceed 2.0 seconds (0.01 mil). Considered accuracy (90 percent + assurance) for use by field artillery survey is 5.0 seconds (0.02 mil).
Second Order Azimuth	An azimuth of a line used in the extension of second order survey

APPENDIX G
TRAVERSE

Computation of Maximum Allowable Radial Error
1:3,000 *or* 1 M $\sqrt{K}$ (to nearest 0.1 K)

DISTANCE MEASURED, METERS	3,000 / TOTAL DISTANCE	1 M $\sqrt{K}$
1,000	0.33	1.0
2,000	0.66	1.41
3,000	1.00	1.73
4,000	1.33	2.00
5,000	1.66	2.24
6,000	2.00	2.45
7,000	2.33	2.65
8,000	2.66	2.83
9,000	3.00	3.00
10,000	3.33	3.16
11,000	3.66	3.32
12,000	4.00	3.46
13,000	4.33	3.61
14,000	4.66	3.74
15,000	5.00	3.87
16,000	5.33	4.00
17,000	5.66	4.12
18,000	6.00	4.24
25,000	8.23	5.00
36,000	12.00	6.00

NOTE. The 1:3,000 evaluation gives a smaller *maximum* allowable radial error through 8,000 meters. The 1 M / $\sqrt{K}$ evaluation gives a smaller *maximum* allowable radial error for 10,000 meters or above.

Fourth Order Azimuth — An azimuth of a line used in the extension of fourth order survey which, from its point of origin at a fourth order astronomic azimuth line or higher order direction, has depreciated in accuracy by a probable error value of 6 seconds (0.03 mil) per main scheme angle, or the azimuth of a line determined by computation between a fourth order survey control point and a survey control point of equal or higher order. In the latter case, considered accuracy (90 percent + assurance) for field artillery survey is 60 seconds (0.03 mil).

Fifth Order Survey — Field Artillery survey performed to an accuracy of a maximum of 1 unit of error in 1,000 similar units of survey. Usually written 1:1,000.

Fifth Order Astronomic Azimuth — A field artillery azimuth established by astronomical methods, the probable error of the result of which does not exceed 24 seconds (0.12 mil). Considered accuracy (90 percent + assurance) for field artillery survey is 60 seconds (0.30 mil).

Fifth Order Azimuth — An azimuth of a line used in the extension of fifth order survey which, from its point of origin, has depreciated in accuracy by a probable error value of 18.0 seconds (0.09 mil) per main scheme angle.

Caution: **A fifth order azimuth cannot be obtained by computation between a fifth order survey control point and a survey control point of equal or higher order.**

APPENDIX I
TIME

I–1. General

a. Time is an angular measurement. One complete rotation of the earth is 1 day. Each day is divided into 24 hours of 60 minutes each, and each minute is divided into 60 seconds. In field artillery computations, angular measurements are usually expressed in mils. Table 5 in the Army Ephemeris is used to convert time to mils.

b. Solar time is the hour angle of the sun plus 12 hours. Since the apparent sun does not move at a uniform rate, time is based on the mean movement of the sun. Greenwich mean time (GMT) is the hour angle of the mean sun from the meridian of Greenwich plus 12 hours. Mean time is the hour angle of the mean sun from the standard time zone meridian plus 12 hours.

I–2. Standard Time and Time Zones

Watch times are based on standard time zones, each of which covers a portion of the earth. In a zone of operation, survey personnel using astronomic observations must know the time zone on which their watch time is based. The time zone on which a watch time is based can be determined from the survey information center (SIC). (Time zone corrections are given as shown in the table below).

Time Zone Corrections, Local Mean Time to Greenwich Mean Time

Time zone		Correction (hours)	Time zone		Correction (hours)
Z	Greenwich (GMT)	0	Z	Greenwich (GMT)	0
A	15° E	—1	N	15° W	+1
B	30° E	—2	O	30° W	+2
C	45° E	—3	P	45° W	+3
D	60° E	—4	Q	60° W	+4
E	75° E	—5	R	75° W	+5
F	90° E	—6	S	90° W	+6
G	105° E	—7	T	105° W	+7
H	120° E	—8	U	120° W	+8
I	135° E	—9	V	135° W	+9
K	150° E	—10	W	150° W	+10
L	165° E	—11	X	165° W	+11
M	180° E	—12	Y	180° W	+12

Note. Each of these zones is named by local civil authority. For example, in the United States, time zone Q corresponds to *eastern daylight saving time;* time zone R corresponds to *eastern standard time* and *central daylight saving time;* time zone S corresponds to *central standard time* and *mountain daylight saving time;* time zone T corresponds to *mountain standard time* and *Pacific daylight saving time;* and time zone U corresponds to *Pacific standard time.*

Local mean time (LMT) changes 1 hour for each change of 15° of longitude. Since the sun appears to move from east to west, time increases from west to east and decreases from east to west. For example, with the Greenwich meridian as a baseline for time measurement, time decreases 1 hour for each change of 15° of longitude (arc) westward from Greenwich. Time differs in whole hours from Greenwich mean time at 15° W, 30° W, 45° W, etc. To standardize the time within a certain area, lines of longitude at which time differs from Greenwich mean time in whole hours

are used. A time zone area extending 7½° from each side of these lines has the same time as that meridian unless otherwise specified by civil authorities. For example, the time zone for the 45° W meridian would extend from 37° 30′ W to 52° 30′ W. In the United States there are four time zones. These zones are based on the 75° W, 90° W, 105° W, and 120° W meridians and are called eastern, central, mountain, and Pacific standard times, respectively.

I–3. Source of Accurate Time

a. All major nations furnish a radio time signal of a high order of accuracy for use by scientists and navigators. The method of obtaining the correct time from such radio signals is explained in detail in TM 5–441. These radio signals are the preferred and most accurate time source.

b.. The survey information center is issued a chronometer which is capable of maintaining time to an accuracy sufficient for artillery survey use. For the use of those artillery surveyors who are not equipped with a radio which will receive the time signals referred to in *a* above, the SIC furnishes accurate time. The SIC maintains, in a bound book such as DA Form 5–72, a log of the chronometer so that time accurate to 0.2 second can be furnished by telephone, radio, or direct comparison of watches to using survey units. (See example below).

SIC Chronometer Log

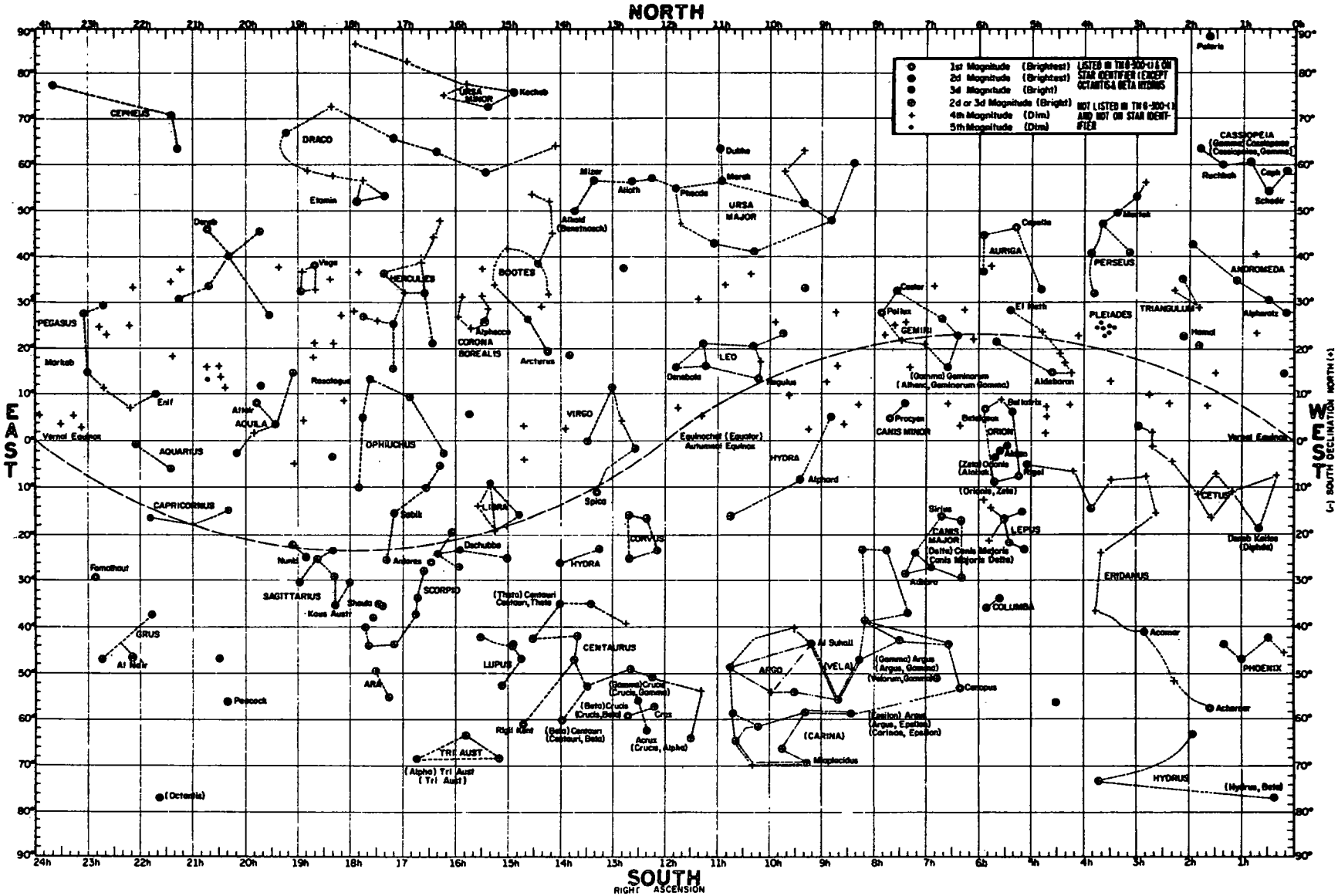
Date	Time	Chronometer			Chronometer correction			Dif sec	Elapsed time days	Daily Rate
		h	*m*	*s*	*h*	*m*	*s*			
Jan 2	0800	08	43	27.3	0	43	27.3			
Jan 3	0800	08	43	29.5	0	43	29.5	−2.2	1	−2.20
Jan 7	0800	08	43	39.1	0	43	39.1	−9.6	4.375	−2.19

The record is kept in the following manner:
The date and time is obtained from one of the radio time signals listed in TM 5–441. Computations can be simplified if the signal is obtained at the same time each day. A comparison of the chronometer time and the radio time should be made to the nearest 1.0 second to provide time accurate to 0.2 second. The chronometer correction at the time of the comparison is the difference between the chronometer time and the time obtained by radio. The sign of the correction should reduce the chronometer time to correct time. The difference column is the change in the correction between the current chronometer comparison and the last chronometer comparison. The sign of this difference should reduce the previous chronometer correction to the current correction. This should be in seconds of time. The elapsed time is the difference in decimal parts of a day between the last two comparisons. The daily rate is obtained by dividing the difference column by the elapsed time in days and carries the same sign as the difference column. The daily rate is a measure of the amount of time the chronometer loses or gains in a day. The chronometer should be wound at the same time each day in order to maintain a uniform rate. The chronometer must never be allowed to run down and should never be set. When the survey information center is moved, the chronometer must be handled with care.

c. Message center time is used to synchronize military tactical operations and, in general, is not accurate enough for astronomic use. However, when observing the stars (sun) by the altitude method, or Polaris by the Polaris tabular method, it will usually suffice. The habit of using time from the SIC should be formed in order to obtain the most accurate time possible.

APPENDIX J

WORLD STAR CHART



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